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PROCEEDINGS OF SYMPOSIUM ON WATER-IN-FUEL EMULSIONS IN COMBUSTI--ETC(U)

SEP 78 R WALTER, J WHITE

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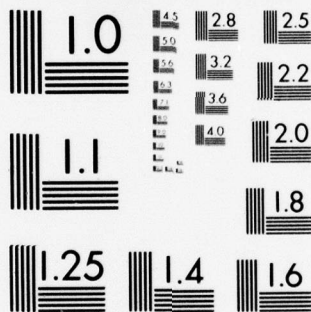
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LEVEL II

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PROCEEDINGS OF SYMPOSIUM ON WATER-IN-FUEL EMULSIONS IN COMBUSTION

Robert Walter (TSC) and James White (USCG), Editors

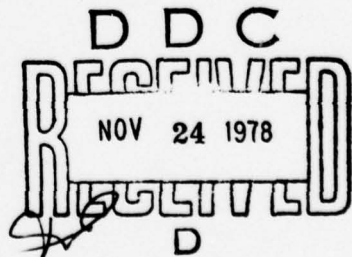
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Transportation Systems Center
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LEVEL II

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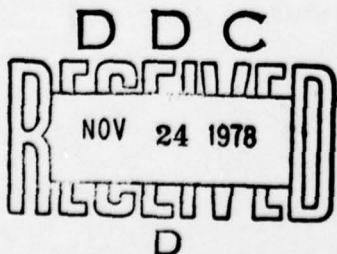
PREFACE

A symposium on water-in-fuel emulsions was held on April 20 and 21, 1977 at the Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts to provide a forum for researchers in the use of water-in-fuel emulsions in the combustion process. Through invited paper presentations and subsequent discussions and comments among the symposium participants, valuable information was made available relative to emulsions in combustion and their practical application in boilers, gas turbines, and diesels.

The proceedings described in this document include abstracts of paper presentations, question-and-answer periods, and comments on the significance of the respective papers. The transcribed statements attributed to presenters and participating attendees have been edited, but only for clarification of the transcriptions.

Identification of the participants in the tape-recorded discussions and clarity of meaning in their statements often depended on recognition by the editors of the speakers' voices and on the quality of the tape recordings. The editors apologize for any misrepresentation or misinterpretation occasioned by this practice.

The editors acknowledge the United States Coast Guard as originator of the idea for setting up the symposium, and the DOT/Office of the Secretary for support. They thank Captain David Flanagan, United States Coast Guard, for his participation as Chairman. They also thank all contributors of invited papers, and all the attendees for their presence at the symposium and participation in the discussions. The contribution of Leon Tritter, of Raytheon Service Company, in the preparation of this document is likewise greatly appreciated.



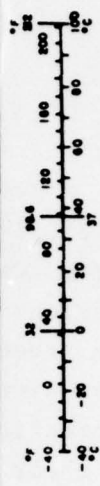
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miles	1.6	kilometers	km
AREA			
square inches	6.5	square centimeters	cm ²
square feet	0.09	square meters	m ²
square yards	0.8	square meters	m ²
square miles	2.6	square kilometers	km ²
acres	0.4	hectares (10,000 m ²)	ha
MASS (weight)			
ounces	28	grams	g
pounds	0.45	kilograms	kg
short tons (2000 lb)	0.9	metric tons	t
VOLUME			
teaspoons	5	milliliters	ml
tablespoons	15	milliliters	ml
fluid ounces	30	milliliters	ml
cups	0.24	liters	l
pints	0.47	liters	l
quarts	0.96	liters	l
gallons	3.8	liters	l
cubic feet	0.03	cubic meters	m ³
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centimeters	0.4	inches	in
meters	3.3	feet	ft
kilometers	1.1	yards	yd
	0.6	miles	mi
AREA			
square centimeters	0.16	square inches	in ²
square meters	1.2	square yards	yd ²
square kilometers	0.4	square miles	mi ²
hectares (10,000 m ²)	2.5	acres	ac
MASS (weight)			
grams	0.035	ounces	oz
kilograms	2.2	pounds	lb
metric tons (1000 kg)	1.1	short tons	ton
VOLUME			
milliliters	0.03	fluid ounces	fl oz
liters	1.1	pints	pt
liters	1.06	quarts	qt
liters	0.26	gallons	gal
cubic meters	35	cubic feet	cu ft
cubic meters	1.3	cubic yards	cu yd
TEMPERATURE (exact)			
Celsius temperature	$\frac{9}{5} (\text{C} + 32)$	Fahrenheit temperature	°F



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SESSION 1
PROPERTIES OF FUEL/WATER EMULSIONS

SESSION 1
PROPERTIES OF FUEL/WATER EMULSIONS

Introductory Statement - Captain Flanagan, Symposium Chairman

I'm Captain Dave Flanagan, of the U.S. Coast Guard. I would like first to thank Bob Walter of the Transportation Systems Center of the Department of Transportation for his great help in setting up this symposium, and the Transportation Systems Center for its part as host. I want to steer the meeting directly to the important issues we are here to discuss, so I will start at once with an introduction of Dr. Robert K. Whitford, representing our host TSC. Dr. Whitford has been Deputy Director of Transportation Systems Center since 1972. Prior to that he was with the TRW Systems Group in California, where he was Manager of the Advanced Electronics Systems Office. Throughout his TRW career he was involved with major aerospace systems. Dr. Whitford.

SESSION 1

WELCOME

ROBERT K. WHITFORD
Deputy Director

Transportation Systems Center
Cambridge, MA

WELCOME
ROBERT K. WHITFORD

Thank you, Captain Flanagan. I am glad, on behalf of TSC, to welcome you all here for this conference. I am fully aware of the importance of water-fuel emulsion and their potential use in all phases of transportation. Therefore, since our prime interest here is to delve into this subject, I will take only enough of your time to acquaint you, as temporary guests of TSC, with an overview of our activities.

TSC is a part of OST (Office of the Secretary of Transportation), which, like the Coast Guard, is a part of DOT (Department of Transportation); we are very happy to support the Coast Guard in conducting this conference. Our function as part of OST is to perform multimodal systems research and analysis. We do both technological work and socio-economic work; actually, we are as concerned about putting in new technology as we are with the impacts and the potential difficulties of trying to implement this new technology. This gets into the full range of economics, sociological impact, and institutional analysis.

I indicated that we provide multimodal support. TSC works with each of the administrations in DOT. For those of you not familiar with the Department of Transportation, I am referring, in addition to the Coast Guard, to the Federal Aviation Administration, the Federal Highway Administration, the Federal Railroad Administration, the National Highway Traffic Safety Administration, the Urban Mass Transportation Administration, the St. Lawrence Seaway Development Corporation, and the Materials Transportation Bureau. Part of our job is to work on some of the common technologies that support a number of those modal administrations.

We are concerned about energy and the environment. We have been deeply involved in noise measurements in support of the Federal Government's investigations of noise sources. We have been heavily involved in investment analysis. A large fraction of the

monies that DOT spends goes for Federal Government efforts to improve the total transportation picture. We are concerned with two problem areas in traffic control: airports and automobiles. There is constant involvement with research and development analysis to effect improvements in both areas. As for future trends in the field of transportation, we also attempt to analyze future demands and to forecast what's going to be required for transportation in the areas of facilities, in the areas of fuel, and in all of the things that affect our transportation business.

Additional important functions at TSC pertain to: minimizing of the fire hazard to subway trains by use of fire resistant materials in subway cars; increasing security at airports by improving weapon detection devices; and improving our system of navigation communication.

Although I have been unable to go into any detail in the few minutes I have addressed you, I trust that you now appreciate the diversity of operations at the Transportation Systems Center, and the opportunity provided us to make significant contributions to the nation's overall transportation capabilities.

And now, I welcome you again to this conference. I hope that your stay here will be a pleasant one, and that the goals you set for yourselves will be met. Thank you.

(End of Dr. Whitford's presentation)

Captain Flanagan

Thank you, Dr. Whitford. We're here to share our information, to learn from each other, to improve our research techniques, our data gathering, and our data reporting on a subject in which we all have considerable interest. We would like to develop, if possible, minimum guidelines for data reporting by the end of the conference. At present, data reporting on water-in-fuel emulsions suffers typically from inconsistency, and from lack of standardization in the computation of water-to-fuel ratios by different researchers. For these reasons, we will benefit greatly by development of minimum guidelines for data reporting, and will be in a

better position to realize the potential for burning fuels previously unacceptable in boilers, gas turbines, and diesel engines.

The conference is being attended by greatly diverse groups. In addition to representatives from seventeen states, we also have attendees from Canada, France, and the United Kingdom. The group interests are likewise quite diversified; they include vendors, academicians, consultants, government workers, and researchers from various segments of government and industry. With such a representation, we can expect the opinions, comments, discussions, and agreed-upon guidelines to carry weight and exercise influence on other researchers in the field who will be made aware of this meeting's results.

We will begin our serious consideration of the subject at hand by first providing a groundwork on the definitions to be used, and then a survey of the present status of the application of water-in-fuel emulsions. I now introduce a gentleman who has contributed much to this field, one who is probably well known to those of you who have researched the burning of hydrocarbons. I refer to Dr. Dryer, of Princeton University. Dr. Dryer.

SESSION 1

OVERVIEW OF STATUS OF
APPLICATION OF WATER-IN-FUEL
EMULSIONS

FREDERICK L. DRYER

Department of Aerospace
and Mechanical Sciences
Princeton University
Princeton, NJ

OVERVIEW OF STATUS OF APPLICATION OF WATER-IN-FUEL EMULSIONS

FREDERICK L. DRYER

Good morning. I'd like to thank the organizers of this colloquium for inviting these overview comments. I recall the first speaker having commented that he only recently became aware of what the emulsion field is all about. Interestingly enough, this experience might also be characteristic among many of the attendees of these Proceedings. Yet the field of emulsion technology and its use as a combustion modifier, while not extending back as far as the almost 200-year-old concept of water addition to combustion,¹ nevertheless began as early as the turn of the century. As for the use of emulsions for some of the purposes that we talk about today, even those interests appeared as early as 1953.² It is a new insight into the effect of emulsified fuel combustion which has caused the recent resurgence in awareness.

Emulsion technology has emerged as a credible field of technical interest primarily because of its relationship to control of emissions from combustion systems. Although in many cases emulsified fuels have been referred to as fuel extenders, I would suggest that this is a misnomer. Rather than being directly involved with improvement in combustion efficiency per se, emulsions provide indirect improvements in operating efficiency through shortening combustion time or relieving emission constraints. These effects can be most notable under operating conditions other than those for which the combustion system was designed and optimized. However, utilization efficiency improvements are generally small. In any case, we should not expect improvements in the vicinity of twenty percent, as reported in some of the trade literature, but gains in the order of one to five percent.

The chairman of these Proceedings has also re-emphasized in his opening remarks that practical, definitive applications research has not been able to identify the extent to which emulsion technology is either economically or technically competitive with other combustion control techniques. This is because the

details of the exact effects of emulsions and emulsion structural properties on combustion have often been ignored in these practical evaluation studies. In this context, I would like to review very quickly some of the properties of emulsion combustion which we now believe are important to optimizing combustion modifications. The first of these properties is emulsion structure.

It is now commonly recognized that the phenomenon of secondary atomization, or "micro-explosions," is often a very important property of emulsion combustion. Secondary atomization optimally occurs over a very short time scale (on the order of less than a few hundred microseconds), and improves the fuel/air mixture homogeneity. It has also been identified, primarily through research at my own institution, that internal phase size distribution has much to do with minimizing the amount of water required to achieve optimal micro-explosive effects. Minimization of water addition may be important, either from the point of reducing system energy losses (boilers and furnaces) or from the point of minimizing required storage (mobile applications). Here, stability must also be considered.

Stability is really the term which distinguishes dispersions from emulsions, and much of the literature that addresses the use of emulsions really is addressing the use of dispersions. Dispersions have relatively high kinetic rates of internal droplet coalescence, and therefore are generally not optimal for secondary atomization.

A second feature which has often been ignored with regard to emulsion combustion is superheating of the internal phase; Dr. Law will address this problem later in terms of pressure modeling on the superheating effect. This work, an outgrowth of earlier observations at Princeton, indicated that before vaporization occurs, the internal phase of an emulsion structure reaches temperatures that are much higher than the normal boiling point, that is, the saturation temperature of the internal phase.³ This phenomenon relates to the fact that the vaporization temperature within a homogeneous medium is determined by nucleation theory. Saturation

temperature must exceed the internal nucleate vaporization temperature for the emulsified droplet if it is to vaporize internally, and this determines under what environmental conditions micro-explosions will occur. For example, in the case of decane/water emulsions, where the boiling point of the external phase (decane) is 174 degrees C, both analytical and experimental work done by us show that the internal phase does not vaporize until having reached temperatures approaching 230 degrees C. Therefore, under atmospheric conditions micro-explosions do not occur for this emulsified fuel. This is not to say that they can't occur at higher pressures, as Dr. Law will describe. In any case, the fuel boiling point range, depending on the ambient pressure, determines when secondary atomization occurs, if at all.

A final potential effect of emulsified fuel combustion is one of modification of the combustion chemical kinetics. Observations have been made which suggest that water addition on the fuel-rich side of diffusion flame structures leads to reductions in gas-phase soot formation. This may be a result of enhanced oxidation of soot precursor species.

In addition to consideration of the parameters that I have just mentioned, one must also be concerned about such physical property changes as effective heat of vaporization, viscosity, surface tension, and the heterogeneity of emulsified liquids (in terms of the effects they may have on primary atomization). All of these areas have received some degree of neglect during practical evaluations; thus, one must reach the conclusion that almost all the practical literature leaves much to be desired on these matters, as well as on the question of how competitive emulsion combustion technology is with other combustion control techniques.

I'd like to conclude this overview with a summary of potentially important applications of emulsified fuel combustion which are based on my own critical review of the field. With regard to internal combustion engines, the use of water addition has often been considered impractical, primarily because of the reflex association of internal combustion systems with mobile transportation.

In this area, however, one should note that there is a significant portion of the current United States stationary NO_x inventory which is produced by stationary internal combustion engines; this area, I think, offers much promise in terms of emulsified fuel application.

While the secondary atomization process probably has little relevance to carbureted spark ignition engines, the use of emulsion structures in direct injection systems may be important. In diesel combustion, emulsions may be a very good technique for improvement of particulate emissions and NO_x control. This area appears to have much promise, and this conference, I hope, will address the problem in some detail. At the same time, we should note that this is not a new area of endeavor. The first extensive emulsion studies in diesel engines occurred as early as 1952;² in fact, it was also recognized at that time that secondary atomization in diesel systems was important. It has been suggested by much of the previous research on diesels that emulsions do not perform as fuel extenders. Specific fuel consumption is changed very little, and, under operation at design conditions, the magnitude of change is similar to what could be done with conventional improvements in injector design, that is, by improving the primary atomization of the fuel. However, in the area of NO_x and particulate control, emulsions offer significant reductions in emissions without the kind of energy utilization degradation that generally occurs with other diesel control techniques.

In the field of gas turbines, you are going to be exposed to two considerations this morning: one of general smoke control, and one of extending the acceptable range of fuel specification for gas turbine systems. I believe the latter area is probably one of the more promising in terms of extending gas turbine fuel supplies (by blending, and other approaches). The area of external combustion will also be addressed in these Proceedings; this has been an area where the fuel extender idea has been espoused by many. However, most of the gains in efficiency in the external combustion field are not due to improvements in combustion efficiency, but to relief in emission characteristics of external combustion.⁴

Finally, there is one very new area of potential use for internal water phase emulsions systems, namely, that of fire safety. Bernard Wright, from Southwest Research, will deal with this problem later in some detail. It's an area which, I think, shows much promise for alleviating liquid fuel fire problems associated with aircraft and ground transportation.

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- 3) Avedisian, C.T. and Andres, R.P., "Bubble Nucleation in Superheated Liquid-Liquid Emulsions," To appear in J. of Coll. & Interface Sci., (1977).
- 4) Dryer, F.L., Rambach, G.D., and Classman, I., "Some Preliminary Observations on the Combustion of Heavy Fuels and Water-in-Fuel Emulsions," Aerospace and Mechanical Sciences Report 1271, Princeton University, Presented at the Central States Section Meeting of the Combustion Institute, Columbus, Ohio, April 5,6, (1976).

(End of Dr. Dryer's presentation)

Captain Flanagan

Well, it's getting interesting already, because there are those here who will try to provide data to show that, in fact, water can be used as a fuel extender. For the record, I happen to be one of them. We will continue now with the first paper of this first session on the properties of fuel-water emulsions. Professor Dooher, of the Center for Energy Studies, Adelphi University, will discuss the subject from his paper titled Rheological Properties of Fuel Emulsions. Professor Dooher.

SESSION 1

PAPER 1

RHEOLOGICAL PROPERTIES OF
FUEL EMULSIONS

JOHN P. DOOHER
Center for Energy Studies
Adelphi University
Garden City, NY

RHEOLOGICAL PROPERTIES OF FUEL EMULSION

JOHN P. DOOHER

ABSTRACT

Data on the viscosity of coal/water/oil emulsions, measured by a Haake Rotovisco, are given. The emulsions were made ultrasonically, using various coals and No. 2 oil. Several concentrations of coal, from 40% to 55%, were tested. The coal size distribution is presented, using a Rosin Rammler fit. A strong dependence between coal type and viscosity and stability under flow is demonstrated. Photomicrographs of various emulsions are presented showing their internal structure.

The flow characteristics of No. 6 oil are also discussed, along with those of emulsions of 15% water and No. 6 oil. The relationship between preheat temperature and viscosity is explored.

(End of Abstract)

Captain Flanagan

Thank you very much, Professor Dooher, for your very informative discussion. Unfortunately, we are still behind in our schedule, so please save your questions for the discussion period. Let us now continue with the next speaker, Dr. C.D. Han, of the Polytechnic Institute of New York. Dr. Han's presentation is titled Rheological Investigation of Fuel Oil/Water Emulsions.

SESSION 1

PAPER 2

RHEOLOGICAL INVESTIGATION
OF FUEL OIL/WATER EMULSIONS

CHANG DAE HAN

Chemical Engineering
Division of Engineering
Polytechnic Institute of New York
Brooklyn, NY

RHEOLOGICAL INVESTIGATION OF FUEL OIL/WATER EMULSIONS

CHANG DAE HAN

ABSTRACT

When two immiscible fluids, e.g., oil and water, are subjected to shear forces, droplets of one phase are produced within the other, forming a dispersed two-phase system, i.e., fuel/water emulsion. The question as to which of the two fluids forms droplets in the other depends on, among other things, the volume ratio of each component, the viscosity ratio of the individual components, and the interfacial tension between the two fluids. For instance, depending on the composition ratio, the less viscous fluids may form droplets and get dispersed into the more viscous fluid, or the more viscous fluid may form droplets and get dispersed into the less viscous fluids. In practice, uniform droplets are not obtainable, and the average size of droplets and their size distribution depend very much on the manner in which dispersion takes place, i.e., how an emulsion is prepared. It should be pointed out, further, that the size of droplets has a great effect on the stability of a dispersed system, i.e., an emulsion.

It has been reported in the literature that the apparent viscosity of emulsions obtained from two mutually incompatible solutions can be lower than that of the less viscous component at certain compositions of the two liquids, i.e., the viscosity-composition curves go through a minimum. This observation is in conformity with the results of experiments by Dr. Han and co-workers, who measured the apparent viscosities of two incompatible molten polymers.

Therefore, a better understanding of the rheological properties of fuel oil/water emulsions is of fundamental and practical importance. For this, research effort is needed to develop experimental capabilities of measuring the flow properties of oil/water emulsions and also, theoretical capabilities of predicting the bulk flow properties of oil/water emulsions.

Also, it has long been known that, under certain flow conditions, droplets suspended in an emulsion break up in the flow through a nozzle. This is of particular importance to a better engineering design of systems which utilize fuel/water emulsions for combustion purposes, e.g., diesel injectors. Therefore, research effort, both experimental and theoretical, is needed to help one establish critical flow conditions at which droplet breakup may occur, in terms of the flow rate (injection speed), the volume ratio of fuel and water, and the size of the droplets in the emulsion.

This paper presents some of the preliminary studies which deal with the flow properties of emulsions consisting of two polymeric fluids, and the phenomenon of droplet breakup in a flow channel.

(End of Abstract)

Captain Flanagan

Thank you, Dr. Han. We have one more presentation scheduled for this first session. Our next speaker is Dr. C.K. Law, from the Department of Mechanical Engineering and Astronautical Sciences, Northwestern University. Dr. Law will discuss the investigation of water-in-fuel emulsion droplet combustion. The title of his paper is An Analysis for the Combustion of Water-in-Fuel Emulsion Droplets. Dr. Law.

SESSION 1

PAPER 3

AN ANALYSIS FOR THE COMBUSTION
OF WATER-IN-FUEL EMULSION
DROPLETS

C.K. LAW

Department of Mechanical
Engineering and Astronautical
Sciences
Northwestern University
Evanston, IL

AN ANALYSIS FOR THE COMBUSTION OF WATER-IN-FUEL EMULSION DROPLETS
C.K. LAW

ABSTRACT

The vaporization and combustion characteristics of a water-in-fuel emulsion droplet are investigated by analyzing the multicomponent heat and mass transport processes in the gas phase and the gasification of an immiscible liquid mixture at the gas-liquid interface. Results substantiate and quantify the postulates that water emulsification reduces liquid-phase soot formation by suppressing the attainable droplet temperature, and reduces gas-phase soot and NO_x formation by suppressing the droplet flame temperature and size and also by enriching the flame region with water vapor. By further comparing the droplet temperature with the limit of superheat of water, it is shown that the occurrence of micro-explosion is enhanced by increasing the ambient pressure, and that at one atmosphere the fuel's boiling point has to be at least as high as that of n-hexadecane in order to achieve micro-explosion.

(End of Abstract)

Captain Flanagan

Thank you, Dr. Law. We will now have a coffee break, after which we will devote our attention to presentations for the second session.

(End of Session 1)

SESSION 2
PRODUCTION OF FUEL-WATER EMULSIONS

SESSION 2
PRODUCTION OF FUEL/WATER EMULSIONS

Captain Flanagan

We will now investigate another aspect of the subject as we enter Session 2 of the symposium, namely, the production of fuel/water emulsions. The first speaker of the second session will be Professor H.S. Fogler, of the University of Michigan. Professor Fogler will speak on acoustic emulsification.

SESSION 2

PAPER 1

ACOUSTIC EMULSIFICATION

H. SCOTT FOGLER
MING K. LI

Department of Chemical Engineering
University of Michigan
Ann Arbor, MI

ACOUSTIC EMULSIFICATION
H. SCOTT FOGLER AND MING K. LI

ABSTRACT

A technique has been developed to study the phenomenon of acoustic emulsification in which oil is dispersed as a fine suspension into water at 20 kHz. The acoustic emulsification process takes place in two stages. In the first stage, large oil droplets are formed from eruption of surface waves at the oil-water interface. In the second stage, acoustic cavitation causes these large drops to break up into smaller drops.

The criterion of instability for the initial stage of emulsification has been derived from a linearized stability analysis of the oil-water interface under acoustic excitation, and the characteristic droplet diameter produced by the instability is related. The amplitude of the ultrasonic transducer and induced capillary wavelength at the interface and the theoretical threshold amplitude of vibration necessary for the instability of the interfacial waves are virtually the same. In addition, the size of the large droplets present in the suspension systems at short irradiation times agrees closely with the predicated droplet diameters.

It is known that intense cavitation shockwaves can be generated in the water medium under the influence of an ultrasonic field. In conjunction with the liquid-liquid emulsification phenomenon, a theoretical model for the deformation and breakup of an oil droplet was examined on the basis of the droplet being exposed to a cavitation shock. A relation from the model is expressed in terms of two dimensionless quantities, the Ohnesorge number and the critical Weber number ratio. These values are then plotted and compared with the ones obtained from the studies on the liquid droplet exposed to shock impact from a gas stream. The remarkable agreement leads one to the conclusion that large oil droplets originally formed from the oil-water interface as a result of the instability were disintegrated into smaller ones by the

cavitation force until a critical size characteristic of the oil-water system is reached.

(End of Abstract)

Captain Flanagan

Thank you, Professor Fogler. We have heard, and will continue to hear, about the importance of droplet size distribution; the difficulty in measuring droplet size and droplet size distribution; the question of what the droplet size should be; and the effect of droplet size on stability and on micro-explosions. These matters, I believe, will be keyed to our later discussions if we are going to make systems practical.

We are doing well on time, but I still would like to hold off on questions until the discussion period. Our next speaker is Professor D.O. Harper, of the University of Louisville. His topic is titled Static-Disk, Spiral-Flow Emulsification.

SESSION 2

PAPER 2

STATIC-DISK, SPIRAL-FLOW
EMULSIFICATION

DEAN O. HARPER

Department of Chemical Engineering
University of Louisville
Louisville, KY

STATIC-DISK, SPIRAL-FLOW EMULSIFICATION

DEAN O. HARPER

ABSTRACT

A static-disk spiral-flow emulsor has been developed and used to prepare (dispersed phase/continuous phase) (1) kerosene/water, (2) isooctane water, (3) carbon tetrachloride/water, and (4) chlorobenzene/water emulsions. With the first two systems, the emulsion performance was evaluated in terms of the two overall pressure drops (between the two pure fluid inlets and the emulsion outlet) and the corresponding power consumption (calculated from the sums of the appropriate products of pressures and flow rates). The emulsions were compared on the bases of light transmittance and coalescence time. With the latter, two systems emulsion characterization was obtained through the use of interfacial polymerization.

In that study a diacyl chloride was dissolved in the inlet organic phase; the inlet water phase was pure. After an organic/water emulsion had been created, it was immediately (and continuously) fed to a product tank containing water with a dissolved diamine. A rapid interfacial polymerization of a polyamide produced a solid shell around the droplets. The shell grew inward within the droplets until the shell inhibited contact between the reactants. The resulting "solid" particles were sized with a Coulter-counter Model TA, yielding log-normal distributions of the Sauter diameter (volume-to-surface ratio) with known averages and standard deviations. These dispersions were shown to be stable for over one year.

A dimensionless group correlation of the Sauter mean diameters permitted both phenomenological (viscous, inertial, centrifugal, and surface forces) and independent variable (flow rates and ratio, densities, viscosities, interfacial tension, and emulsor diameter and thickness) analyses. Data from 44 runs resulted in the equation

$$Sn = 6.54 Bn^{0.19} Re^{-1.34} Th^{-0.5} We^{-0.08}$$

where

Sn, size number	$\equiv dp/t$
Bn, Bond number	$\equiv Q^2 \Delta\rho/D^2\gamma t$
Re, Reynolds number	$\equiv Q\rho/D\mu$
Th, Thompson number	$\equiv t/D$
We, Weber number	$\equiv Q^2\rho/D^2\gamma t$

$$\text{Bn, Bond number} \equiv Q^2 \Delta\rho/D^2\gamma t$$
$$\text{Bn, Bond number} \equiv Q^2 \Delta\rho/D^2\gamma t$$
$$\text{Re, Reynolds number} \equiv Q \rho / D \mu$$
$$\text{Th, Thompson number} \equiv t/D$$
$$\text{We, Weber number} \equiv Q^2 \rho / D^2 \gamma t$$

with

- dp - particle Sauter mean diameter
- D - emulsor diameter
- Q_1, Q_2 - inlet flow rates of continuous and dispersed phases, respectively
- $Q = Q_1 + Q_2$
- t - emulsor thickness
- α - volume fraction dispersed phase = $(1 + (Q_1/Q_2))^{-1}$
- γ - interfacial tension
- ρ_1, ρ_2 - densities of continuous and dispersed phases, respectively
- ρ - emulsion density = $\rho_1 + \alpha \Delta\rho$
- $\Delta\rho$ - density difference = $\rho_2 - \rho_1$
- μ_1 - viscosity of the continuous phase
- μ - emulsion viscosity = $\mu_1(1 - \alpha)^{-1.75}$

D - emulsor diameter

Q_1, Q_2 - inlet flow rates of continuous and dispersed phases, respectively

$$Q = Q_1 + Q_2$$

t - emulsor thickness

$$\alpha - \text{volume fraction dispersed phase} = (1 + (Q_1/Q_2))^{-1}$$
 γ - interfacial tension

ρ_1, ρ_2 - densities of continuous and dispersed phases, respectively

$$\rho - \text{emulsion density} = \rho_1 + \alpha \Delta\rho$$
$$\Delta\rho = \text{density difference} = \rho_2 - \rho_1$$
 μ_1 - viscosity of the continuous phase
$$\mu - \text{emulsion viscosity} = \mu_1(1 - \alpha)^{-1.75}$$

Thank you very much, Professor Harper. We now turn our attention to another approach to the production of emulsions, specifically, water in diesel fuel emulsions. This approach will be discussed in the paper titled Prototype Development for On-Line Emulsification Through Cavitation of Diesel Fuel with Water, to be presented by Mr. J.P. Cavanaugh of Daedalean Associates, Inc. Mr. Cavanaugh.

Thank you very much, Professor Harper. We now turn our attention to another approach to the production of emulsions, specifically, water in diesel fuel emulsions. This approach will be discussed in the paper titled Prototype Development for On-Line Emulsification Through Cavitation of Diesel Fuel with Water, to be presented by Mr. J.P. Cavanaugh of Daedalean Associates, Inc. Mr. Cavanaugh.

SESSION 2

PAPER 3

PROTOTYPE DEVELOPMENT FOR ON-LINE
EMULSIFICATION THROUGH CAVITATION
OF DIESEL FUEL WITH WATER

J. P. CAVANAUGH
A. THIRUVENGADAM
A. HOCHREIN

Daedalean Associates, Inc.
Woodbine, MD

PROTOTYPE DEVELOPMENT FOR ON-LINE EMULSIFICATION THROUGH
CAVITATION OF DIESEL FUEL WITH WATER

J.P. CAVANAUGH, A. THIRUVENGADAM, AND A HOCHREIN

ABSTRACT

A prototype emulsifier has been developed to evaluate a concept of producing fuel emulsions on-line in Coast Guard vessels. This paper examines the equipment requirements of a prototype device utilizing the phenomenon of cavitation for emulsion formation. It is shown that stable emulsions of varying concentration of water in diesel fuel can be produced by this process without the use of surface active agents. The total energy rate into the emulsifier is described as a function of concentration, quality, and amount of emulsion produced.

(End of Abstract)

Captain Flanagan

Thank you, Mr. Cavanaugh. We will now hear from Dr. R. C. Little, whose subject will be Some Generalized Considerations in the Production of Chemically Stabilized Emulsions. Dr. Little.

SESSION 2

PAPER 4

SOME GENERALIZED CONSIDERATIONS
IN THE PRODUCTION OF CHEMICALLY
STABILIZED EMULSIONS

R.C. LITTLE
R.L. PATTERSON

Naval Research Laboratory
Washington, DC

SOME GENERALIZED CONSIDERATIONS IN THE PRODUCTION
OF CHEMICALLY STABILIZED EMULSIONS

R.C. LITTLE AND R.L. PATTERSON

ABSTRACT

If the factors involved in emulsion stabilization are known with any degree of certainty, a strategy can presumably be devised by which such emulsions can be conveniently prepared or demulsified. In order to understand emulsification and the opposite process of demulsification, one must have meaningful information on the chemical components involved in the emulsification process; specifically, water, oil and agent. Of the three components, only water is invariant. In other words, the nature of both the oil and the stabilizing agent may vary considerably. Nonetheless, it is strongly suspected that the most effective agent to be used in stabilizing a given emulsion will be dictated to a certain extent by the nature of the oil phase.

In order to understand the emulsification process, it is useful to employ some scheme of rating the components involved. In the case of the stabilizing agent, a numerical scale, the so-called HLB system, exists. HLB stands for the hydrophilic-lipophilic balance of the emulsifier molecule, and is determined through a series of experimental emulsion tests for each agent. The optimum HLB for a given surfactant to emulsify an oil will be dictated by the solubility parameter of the oil. Where the attractive forces between oil molecules are low, as in the case of low molecular weight aliphatics, the stabilizing agent should have an HLB of 11 for the optimum effect. For aromatics such as benzene, where the intermolecular forces are higher, the optimum HLB is four units greater. It is now possible to assign numerical indices to both components of the emulsion which are expected to be variable, i.e., solubility parameter for the oil and HLB number for the surfactant.

The last and most important factor is the nature of the interface itself. Sturdy interfacial films can be produced by the formation of semisolid interfacial material through absorption

processes, liquid-crystal formation, and even poorly wetted finely divided particulates. The interfacial factor can probably be indexed through the use of phase diagrams and force-area curves developed from measurements at the liquid-liquid interface. The combustion characteristics of chemically stabilized emulsions must, to some extent, be dependent upon the type of interfacial structure produced by the surfactant in the presence of the oil and water phases.

(End of Abstract)

DISCUSSION PERIOD

Captain Flanagan

In order to ensure a reasonable order to the discussions, and if there are no objections or other suggestions, I will call for questions for each of the gentlemen who presented comments on specific topics. First, would anyone like to address any questions or make any comments relative to Dr. Dryer's opening remarks? Yes, Dr. Dooher.

Professor Dooher

You appeared to imply that, from your standpoint, the explosion phenomenon does not seem to be significant. Is that your thinking now, Fred, in terms of, say, boilers?

Dr. Dryer

Absolutely not. That's not my thinking at all.

Captain Flanagan

After having talked with you, I'm also sure it isn't.

Dr. Dryer

It's quite possible that in boilers or gas turbines secondary atomization becomes very important. As Dr. Law has shown, it takes a rather high boiling point range in some cases; however, in all cases of the two fuels we've just mentioned, particularly the case for residual fuel oil, the end boiling point range for those materials extends well above the temperatures necessary for

homogeneous nucleation without any nucleation sites. In most of those fields there is also enough particulate contamination, cavitation bubbles (air bubbles if you will), as well, which can cause nucleation sites; so indeed, the secondary atomization is important in those cases. I did mean to suggest that, in the case of diesel combustion in which injector modification has been made to cause ultimate atomization, it does not appear to me that one can talk about significant improvements in specific fuel consumption due to improved atomization or secondary atomization effects. One can still talk about emission improvements and buy back certain improvements in specific fuel consumption that may have been lost through other control techniques.

Captain Flanagan

Any further questions for Dr. Dryer? Now, Dr. Dryer, in your last statement relative to diesels, you stated that as far as fuel consumption is concerned in the diesel case, if the injector and combustion system is properly designed, the probability of significant fuel savings is very low, in your opinion. Would you comment on the probability of that injector design being optimum at off-load conditions?

Dr. Dryer

I think that's probably an area where there is some possibility for improvement if one is talking about full-load operations. Generally, injector systems are designed for full-load operations. Therefore, that's the place where you'll probably find least data on specific fuel consumption. It may interest you to know that I'm drawing my comparison from two papers published in 1953 and in 1955 on the studies of emulsified fuels in diesel combustion systems - one on a Witte engine, and one on a General Motors two-cycle, three-cylinder system. Those studies indicated that under very high-pressure atomization conditions, the kinds of specific fuel improvements that one could buy were very small. In the case of low-pressure atomization systems in more fully atomized systems, the benefits in specific fuel consumptions were rather large, in the vicinity of 8%. In the other cases, they were more nearly

1 or 2%; and in some cases, there were detrimental effects of 1 or 2%. But even the detrimental effects of 1 or 2% are small compared to the losses of 5 to 7% in specific fuel consumption through trying to control NO_x through recirculation in diesel systems.

Captain Flanagan

Well, we will devote a good deal of attention to diesel engines and to burning of emulsions in diesels. We'll get into this in considerably more detail tomorrow. Are there any further questions for Dr. Dryer?

Dr. Moses

Yes, I'd like to point to an interesting example with respect to what Fred said. I'm aware of a paper which claimed that some increases in fuel consumption (assuming combustion system efficiency to be interpreted in this manner) were found in turbine combustion. In fact, in this particular example they were trying to burn a more viscous fuel than that for which the engine was designed, and they were trying to use emulsion to help promote the atomization of the fuel. In this case, over a very limited range, they did see an initial improvement in combustion efficiency; but, as they went to higher water concentration, they began to see the penalty that one normally sees in loss of combustion efficiency.

Captain Flanagan

Well, we have people here today who have been extremely successful in burning off-spec fuel (that you might classify as really bad stuff) in marine gas turbines through the use of fuel-processing systems, with water emulsion as the last stage. We'll get into that before the symposium is over. Now, are there any questions for Professor Doohar? Dr. Dryer.

Dr. Dryer

John, I have a couple of questions. In your studies on rheology, as Tom pointed out, the fluctuations of internal phase size can have a significant effect in causing anomalous rheology characteristics in these systems. I wonder whether you looked at internal phase size distribution. The second question has to do

with the fact that one of the other important parameters in atomization, in fact the important parameter in atomization, is surface tension. Viscosity affects atomization primarily through the head velocity that arises at the atomizer. What is effective in terms of spray droplet size is the surface tension. Yet, I noted this morning that very little was done with regard to how surface tension is affected in these systems. I was wondering if you were looking into that.

Professor Doohar

With respect to your first question, it's very possible that when these emulsions begin to break, you get large flocculates which cause a lot of these irregularities. I would suspect that's true. To actually look at that is not a very simple thing. You can't just take it out to a microscope as it turns and look at it; there are ways of doing that, but at present we're not looking at that. Right now we are trying to set up the Rotovisco as a capacitor and observe changes in capacitance representing fluctuations. That's certainly an important approach to detecting large fluctuations.

As far as the relationship between surface tension and viscosity and atomization is concerned, it depends on whose theory you want to believe. There are different correlations involved; for example, in an air atomizing system, viscosity and surface tension appear to be very important factors.

Dr. Dryer

I wonder if you have a complete development of head velocity.

Professor Doohar

Yes. As far as surface tension is concerned, I guess your question is, "Are we looking at the surface tensions of these emulsions?" At present we're not looking at the surface tension. The du Noüy Ring Technique is probably one of the better techniques for the surface tensions; we have not looked at surface tensions.

Captain Flanagan

Any other questions for Professor Dooher?

Dr. Schwartz

Have there been any reasonable size industrial tests of coal, oil, and water?

Professor Dooher

Yes. General Motors Corporation has, for about a year or two, been running coal-water-oil tests at a boiler plant. Some of their results are quite interesting. One test result, in particular, had to do with the prevailing concern about ash deposits on boiler tubes. The tests appear to indicate that 99% of the ash goes out of the stack, which means that you're not going to have detrimental effects on your boiler tubes. This was a very good result. ERDA (Energy Research and Development Administration) also has a large project, a program to do demonstration studies on coal-oil suspension.

As far as I can determine, there is no large full-scale test on coal-water-oil emulsions. Most of the testing is on coal-oil suspensions.

Dr. Schwartz

Do you have an intuitive feeling as to what types of combustion performances you might expect from coal-water-oil systems?

Professor Dooher

Basically, the combustion performances should be similar to those on coal-oil systems, with perhaps some additional benefit due to the explosion phenomenon in terms of atomization and excess air required.

Dr. Schwartz

Our internal economic analyses on the use of coal and oil emulsified systems have not been highly favorable. One of the reasons is this overall matter of emulsion stability.

Professor Dooher

That's right.

Dr. Schwartz

Do you have any feelings as to what kind of stability in terms of time we're talking about here? Do you think these emulsions are potentially stable over long periods of time, i.e., periods of weeks or months, such that emulsification could occur in a central processing plant and fuel could be shipped as usable fuel for any industrial or utility applications to destinations without on-site capability?

Professor Dooher

I think that on certain coals that have been tested, this is a definite possibility. For example, the best emulsion we had was made with a coal having the Penn. State designation P.S.O.C.99. That was run after several weeks, and we got exactly the same rheogram as we had initially.

Captain Flanagan

Now, is this with water?

Professor Dooher

This is with water and No. 2 oil. With No. 6 oil you will improve the stability. So I certainly suspect that this would be a feasible case, not on all coals, but certainly with some.

Captain Flanagan

Right. Are there other questions? Please identify yourself, sir.

Dr. Spadaccini

Some of your comments related to No. 6 oil-water emulsions. You pointed out the problem with increased water concentration and increasing viscosity. In the example in which you assumed 15% water, you reached the conclusion that to reduce the fuel viscosity you couldn't preheat the fuel high enough to get the viscosity down to the original value. We would agree with that, but I guess it hasn't been demonstrated that 15% water is necessary to

achieve the benefits of emulsification. You can get significant benefits at 5, 6, 7, or even up to almost 10%; in these cases, fuel preheating is not a severe problem.

Professor Dooher

The 15% figure, based on some of our tests on boilers, is about the ultimate figure with the type of emulsifier we are using. It's conceivable that you can use half of that and still get the same type of results. It depends on what you're looking for.

Dr. Spadaccini

It depends on lots of things, such as particulate size and distribution.

Professor Dooher

So, with smaller emulsions, you can perhaps achieve the same viscosity.

Dr. Law

In your last picture you show an explosion with the droplets. Were the droplets suspended?

Professor Dooher

Yes, they were suspended droplets.

Dr. Law

Well, then, so far you have not observed free-fall explosions?

Professor Dooher

Well, we dropped them and they exploded. But in terms of taking a high-speed photograph, these are suspended droplets.

Dr. Law

But you have also observed free droplets?

Professor Dooher

Yes.

Dr. Law

Of coal-water-oil?

Professor Dooher

Yes.

Dr. Dryer

I have two comments to make. The first is with regard to coal-water-oil systems. One of the more important aspects I see with respect to dispersions is in the de-agglomeration of ash particles as combustion occurs. One can imagine that the solid components in such a dispersion are going to burn last. Because they are surface burners, they are diffusion governed. This means that with the amount of liquid left in this case, these solids become concentrated. One then finds that whether particles are divided as 20 microns or as 30 microns, burning creates an agglomerate of a much larger size particle. And in this case, if one can get the secondary atomization type process, one will get a de-agglomeration of those particles. The characteristics of combustion are representative of a much smaller particle size as far as the solid is concerned.

My second comment is that there are some data available in this area of an empirical nature of the viscosity characteristics of residual oil emulsions - in particular, data published by the Battelle Memorial Institute in 1968 and 1970. Studies were made on about fifteen different representative samples of residual structures, and they have published data very similar to the kind of thing that Professor Dooher is talking about.

Captain Flanagan

Thank you, Dr. Dryer, Yes, sir.

Professor Essenhigh

I'd like to ask the people here for a general opinion on the importance of stability. Look at oil-water emulsions. If you form your emulsion right by the furnace and then run it in, your residence time is maybe half a second, and then you don't care. Do you really want to go for stability there? We do the same thing with forming coal-oil dispersions and, as I'll mention later,

we do this in two stages. The second stage consists of putting in the initial stable coal-oil dispersion and then diluting it. Again, you're not too much concerned about stability, because you are putting it directly into the furnace, and you don't care. The first stage, the question of having central plants and then shipping it out, leads one to think at first that you do need to have this stable. Then you think that maybe you don't. Perhaps you can just have it semi-stable, and ship it out the way you ship out concrete in a rotating drum or something like that. It may be very much cheaper to do it that way. You have to think about distances, but maybe that's the way to go. I wonder if anybody has any comments about that.

Captain Flanagan

I would think that, knowing what's to come, we're going to be looking at on-line emulsions right next to the combustion process; we're looking at surfactants in stabilized emulsions produced in bulk and used later. Your concept of the halfway/in-between is most interesting; I haven't heard anybody talk about that yet. I believe this is more appropriate for a later wrap-up discussion, because we have a lot of ground to cover yet, and you're going to see some practical applications of on-line emulsions which have in fact worked. So, while I think it's excellent food for thought, I'd like to defer discussions on the benefits of bulk versus on-line emulsions until later, because we have some presenters who can provide some valid data on the subject. Well, moving on, are there any more questions for Professor Dooher? For Dr. Han? Dr. Law, on analysis of combustion - water-fuel emulsion droplets? Yes, sir?

Dr. Zwillenberg

I didn't quite understand the assumption that the evaporation rate of the water and fuel mixture is proportional to their relative proportions. Doesn't the volatility have something to do with that?

Dr. Law

It's related to the assumptions of the liquid phase description. If I assume there's no mass transfer from liquid phase, then they have to come out. The way they come out has to be governed by the concentration in the liquid phase, which will be the original concentration.

Captain Flanagan

Yes, Dr. Dryer.

Dr. Dryer

I have a comment on that question. When I referred to chemical kinetics in my initial overview, I was not referring only to the effects of pollution. Some effects which occur represent actual chemical kinetic involvement of the water vapor in the process of soot formation or precursor oxidation. So it's more than just the pollution effect. Ed, I'd like to ask you how you extend your arguments for single droplets to actual array burning, since most practical combustion systems are actually array burning systems.

Dr. Law

Well, there are two cases: droplet vaporization, and droplet burning. If you talk about array burning, that means group burning. In group burning, you have essentially a group of droplets which individually vaporize and give out a fuel vapor, and burn as an envelope to the whole group. This is one mechanism I'm referring to; but in this analysis, the first thing you really have to know involves the individual vaporization mechanisms.

Dr. Dryer

Do you believe that the thin sheet model for flame still applies in the array burning case?

Dr. Law

This is a highly controversial item. In fact, in the last few years, at just about every meeting on combustion, debate has centered on whether there is a single drop burning or group

burning. As of now, we have no really definitive answer. Chigier, of Sheffield University, has insisted that there is group burning, and some experimental evidence appears to support this view, although the experiments must be run under very special conditions. In the final analysis, however, one must know the rate of oxidizer entrainment in the fuel spray.

When the fuel spray is injected into a combustor, the rate of oxidizer entrainment into the fuel spray interior, and hence the rate of delivery of oxygen to the droplet region, determines the nature of combustion support. Specifically, if the rate of entrainment is very slow, there will not be enough oxygen in the spray interior to support individual droplet combustion, and group combustion occurs. If, on the other hand, the initial rate of oxidizer entry is large, then individual droplet burning is possible. Much work remains to be done on this problem. I, for one, am interested in it, and am also working on it.

Captain Flanagan

There is another gentleman back there who wishes to speak.

Professor Henein

In the area of diesel combustion, the fuel is injected at the supercritical pressure of almost every component of this distillate fuel. Under the condition of supercritical pressure, droplet evaporation does not occur. As the temperature increases to the value of critical temperature, the droplet just disappears. Now, if water is added, the supercritical pressure becomes much higher, resulting in fuel evaporation and the simultaneous existence of liquid droplets. Has this been taken into account in your model?

Dr. Law

Well, it takes time for the emulsion droplets to be heated to the critical temperatures. There are two critical temperatures: the critical temperature for fuel, and the critical temperature for water. Of course, what you are saying is that the water has the higher critical temperature. But overall it takes some time

even for the emulsion droplet to reach that critical stage. So, before it reaches that critical stage, it still behaves as a liquid.

I don't quite understand you. You say there is no vapor around the droplet, because there would be heat going into the droplet. Heat of vaporization is another matter, but there would certainly be vapor around it, in the vicinity of the droplet.

Professor Henein

We will deal with this some more in tomorrow morning's session. We will be introduced to more details of the combustion problem.

Captain Flanagan

Well, with this aspect of the problem solved for the present, let us move on.

Professor Essenhigh

I'd like to come back to the point about the burning droplets and the flamelets around them. I'm inclined to agree that the balance of the evidence is in favor of sheet flames, so that we have not only spray, but also the flame outside the spray. Chigier's photographs seem to support that very well. Certainly, as you get far enough downstream, and there is the better chance for oxygen to diffuse in, you're likely to change to a different system. But, from the standpoint of calculated burning time, with variations in the flamelet from ten radii to infinity, it makes at most about 10% difference in burning time. So, it really doesn't matter if you consider the flame at infinity, which is equivalent to evaporation, or close to it. It's only when you get to within about five radii or less that this really becomes important. So, from one point of view, I think it's almost a redundant question. If you can't do a large-scale experiment with sufficient sensitivity to say definitely where the flamelet is, then it becomes unimportant. The matter has been given far too little attention, although perhaps you remember, as I do, experiments done about twenty or twenty-five years ago by Burton and Cole.

Anonymous

Yes, spray.

Professor Essenhigh

Well, this wasn't spray, this was a falling tube. What they found there was that they could see directly the larger drops, the drops with the little flamelets around them, about 40 to 50 microns and larger. For eight microns and below, they stated categorically that there are no flamelets; the thing just evaporates. If there did exist a transition range, they were not quite certain whether it consisted of a narrow band, or where the actual cutoff occurred. They came to the conclusion that on the number size distribution, the majority in terms of number vaporized anyway before any flamelets were formed, although on the mass basis this may not be the case. Perhaps about half of the drops vaporized; they never had a chance to form their flamelet.

Dr. Law

I'm inclined to agree with you that one shouldn't try too hard to distinguish between droplet vaporization and droplet burning. Droplet burning just gives you an additional heat flow source around the flame, so you can arbitrarily think of a hotter source. People have begun of late to become interested in why one would want to look into droplet combustion. For my part, in the special case of droplet vaporization you can artificially keep a large heat source.

Professor Essenhigh

Well, I'd like to offer a qualifying statement on that. We studied the combustion of polymers, and found that these were burning two or three times faster than oil drops. The molecular fragments coming off the surface were so large that the diffusion coefficients were very low, and the flamelet around it was then so close as to accelerate the heat transfer and accelerate the burning rate. So, in limiting conditions like that, yes, it can give you difference factors of two or three rather than a mere ten-percent difference.

Dr. Law

But the basic mechanism of vaporization at interfaces is the same.

Professor Essenhigh

It was a different heat loss. We used the same model, except that we couldn't assume the temperature was fixed. The temperature was rising as the thing burned.

Dr. Law

Sure, as the droplet proceeded on.

Professor Essenhigh

No, not the droplet. There's no boiling point with polymers. With the polymers there is no fixed boiling point, so you can't talk about its heating up; you can merely say it's rising in temperature.

Dr. Law

That's heating up, isn't it?

Captain Flanagan

All right, gentlemen, are you finished?

Dr. Law

Well, I have a second problem about the Burton and Cole experiment. That experiment, I think, is one-dimensional, so they don't have to solve for that entrainment problem.

Professor Essenhigh

It was a vertical tube, premix, so it was one-dimensional in that sense. It was a traveling flame system, and what I'm saying is that they could see the individual flamelets around the drops, about 40 or 50 microns. Below that, it was very indistinct.

Dr. Law

Below that the smaller droplets were vaporizing. They were burning as a premixed flame.

Professor Essenhigh

Right. They were burning as a premixed flame.

Captain Flanagan

Dr. Dryer, a short comment from you.

Dr. Dryer

Yes, sir. There are two very interesting experiments which go along with the Chigier experiment. One, by Polymeropoulos and Sernas of Rutgers, investigates the change in initial propagations of droplets of arrays. The findings from this experiment again indicate the droplet combustion generally occurs as an after-burning sequence for sizes above the 20-micron range. The second experiment is described in a paper delivered last fall by Dan Rosner at an ACS meeting. The paper, dealing with criteria of delaying combustion, also suggests that array combustion is much more important than single droplet combustion.

Captain Flanagan

Gentlemen, it's getting a little late. However, if there are still questions for our speakers, we will entertain them now.

Dr. Morrone

Yes, I'd like to ask this question of Professor Fogler. I'd like to know about the occurrence of vapor bubbles, or air bubbles, in emulsions produced electronically. Do they exist? Do you have to take pains to make sure that they don't occur?

Professor Fogler

The work we performed was not electronic in nature. We used ultrasonic waves, just tuned pulses going through the system.

Captain Flanagan

I assume you are referring to acoustically produced emulsions. Is that correct?

Professor Fogler

There's a difference. We aren't passing any sort of electronic waves through the systems to form emulsions. You can't do that

when you have a two-phase system; you can't form emulsions by passing electric current through.

Dr. Morrone

I didn't suggest that. I would like to know the extent of occurrence of air bubbles in the emulsion. Do you have to take pains to keep them out? How often do they occur?

Professor Fogler

Well, I think that if there had been bubbles, they possibly could have showed up in the micrographs, perhaps as a hollow sphere. Let's take, for example, C-28S, which was emulsified, and which almost instantaneously solidified. If air bubbles had occurred, we should have been able to detect some of them in the system. We did not find any. I don't think it's really a problem at all.

Incidentally, I would like to acknowledge that much of this experimental work was done by one of my doctoral students, M. Ky Lee, who is now with General Electric.

Dr. Moses

I also have two questions for Dr. Folger. First, am I assuming correctly that you were working with the oil droplets dispersed in the water?

Professor Fogler

That's right. With the current studies we were doing oil droplets dispersed in the water.

Captain Flanagan

That's a very important point, gentlemen.

Dr. Moses

It's an extremely different problem from what we're working with.

Captain Flanagan

Yes, oil-in-water versus water-in-oil. I think you should all recognize that the presentation provided by Professor Fogler did refer to oil-in-water, not water-in-fuel.

Professor Fogler

In our most recent findings, which essentially involved viscosity ratios, it was indicated that when styrenes were dispersed into water, there was an inversion of the viscosities analogous to the dispersing of water into oil, and the viscosity of water was found to be less than the viscosity of the oil. We hope to extend these studies.

Captain Flanagan

I have a question for you relative to your polymerization means of measuring droplet size and distribution. You did it with oil in water. Could this be used as a method of identifying particle size and distribution for water into oil?

Professor Fogler

I think that if you did that you might look at the technique that was discussed by Professor Harper of the University of Louisville. We have used this technique, where you use membranes to surround the oil and form microencapsulations of the water and oil material. We've looked at encapsulating enzymes with this technique, where we emulsified the water in oil. And then after we did that, we formed a membrane and tried to keep the droplets. So, we have studied the reverse phenomena with an entirely different application.

The results are essentially the same. The problem comes in measuring the particle size, because when you put these under an SEM (scanning electron microscope), they collapse. It's very difficult to get just the right thickness of the membrane so that these particles will not collapse when you can see them.

Captain Flanagan

It's a whole new project in itself.

Professor Fogler

Yes.

Dr. Moses

I have another comment to make, perhaps academic in view of the response to my previous question. I have heard a couple of generalizations made that this could be done without a surfactant, as if it applies to all water-fuel systems. I think we need to be careful in our generalizations. Maybe in one particular water-fuel mixture with a certain kind of fuel they were able to do it without surfactants, but that doesn't mean that the same thing will apply to lighter viscosity fuels.

Captain Flanagan

Your cautioning us to be careful is well taken. Thank you very much, gentlemen. It's lunch time, so let us adjourn for a couple of hours.

(End of Session 2)

SESSION 3

EMULSION COMBUSTION TEST RESULTS -
FURNACES, BOILERS, AND GAS TURBINES

SESSION 3
EMULSION COMBUSTION TEST RESULTS -
FURNACES, BOILERS, AND GAS TURBINES

Captain Flanagan

I welcome you to the third session of the symposium. The topic of interest for this session centers on test results relating to combustion of emulsions. The first presenter for Session 3 will be Professor Essenhigh, of Pennsylvania State University. His paper is titled Influence of Particulates on Thermal Efficiency in Emulsion Firing. Professor Essenhigh.

SESSION 3

PAPER 1

INFLUENCE OF PARTICULATES ON
THERMAL EFFICIENCY IN EMULSION
FIRING

ROBERT H. ESSENHIGH
ANGELOS KOKKINOS

Combustion Laboratory
Pennsylvania State University
University Park, PA

INFLUENCE OF PARTICULATES ON THERMAL EFFICIENCY
IN EMULSION FIRING

ROBERT H. ESSENHIGH AND ANGELOS KOKKINOS

ABSTRACT

In previous reported studies of oil/water/air (MDG) emulsions, the thermal efficiency of a hot wall furnace with water tubes on the furnace floor was found to fall with increasing water content in the emulsion. The effect was attributed to change of flame emissivity, since gas temperatures rose. Addition of particles at very low loading restored the heat transfer. Extension of those particle addition studies to higher concentrations has now shown that the efficiency improvement peaks, and then declines. In a first sequence of experiments using the original can-type burner, particles were supplied to the flame by operating beyond the smoke point (from +10% to -5% excess air). Even at 90%, smoke particulate measurements showed less than 1% combustible loss, so the effective thermal input hardly changed. In a second sequence of experiments, using a commercial (York-Shipley), air-atomizing burner, coal was added to the emulsion, with adjustment of the oil rate in this instance to maintain the thermal input at about 1.25 million Btu/hr and excess air constant. Efficiency peaked at about 50% smoke at all water levels up to 37.5%, although particle concentration declined. Efficiency peaked at about 5% coal in the coal/oil dispersion at 10% water and 20% excess air.

The behavior is attributed to a complex balance between heat received by the load (water tubes on the furnace floor) directly from the flame and by that received from the roof and walls but attenuated by transmission through the flame. With a low emissivity flame, two thirds or more of the heat picked up by the load comes from the roof and walls. As flame emissivity (absorptivity) rises, there is more direct heat transfer from the flame, but more of the roof and wall radiation is absorbed by the flame

gases. Initially, the flame contribution increases with a less-than-corresponding decrease in the roof and wall contribution, and the net rises. At high emissivities, the reverse is the case, and the net falls. The result is the efficiency peaking observed. Further substantiating this interpretation, gas temperatures fell as efficiency rose at constant excess air (coal addition), and vice versa. In the smoke experiments, interpretation is more complex, since there is improved efficiency due to reduced excess air. This, however, accounts for only about half the efficiency increase. Moreover, gas temperatures were broadly unchanged, whereas they would have increased had the efficiency improvement been due to reduced excess air alone.

Some practical and theoretical implications of these results are also discussed.

(End of Abstract)

Captain Flanagan

Thank you, Professor Essenhigh. We will now hear from Dr. A. J. Shaler of SMS Associates. The title of his presentation is: Preliminary Field Tests of Micro GasTM Dispersion Fuels. Dr. Shaler.

SESSION 3

PAPER 2

PRELIMINARY FIELD TESTS OF
MICRO GAS DISPERSION FUELS

AMOS J. SHALER

SMS Associates
State College, PA

PRELIMINARY FIELD TESTS OF MICRO GASTM
DISPERSION FUELS
AMOS J. SHALER

ABSTRACT

Tests on the laboratory scale (0.5-1.25 MBtu/hr) have shown that the comparatively low-cost MGD fuels made of No. 2. oil, water, and the extremely fine dual-interface air bubbles characteristic of MGD's can, with use of a simple add-on MGD generator and no substantial burner modification, be substituted directly for natural gas in radiant-tube furnaces, without burning out the tubes and without modifying the air controls.

The results of some very preliminary field firings are given. These were carried out on operating furnaces at Federal-McGul Corporation (Lancaster, PA) and at General Motors Corporation (Sandusky, Ohio). There have as yet been no extended operations. The results of the preliminary field tests show that the peak heat flux is indeed brought down to a level where radiant tubes can be fired with oil-based MGD fuels without burning out the tubes, and that soot emissions are adequately less than with oil alone.

The MGD generators used in the field were of prototype nature, and engineering effort is currently underway to redesign them into reliable commercial equipment.

Meanwhile, tests continue in the third year at the laboratory level, the emphasis having been shifted to coal additions to the oil/water/air MGD fuels. Concentrations have reached 20% coal, 20% No. 6 oil, 47 1/2% No. 2 oil, and 12 1/2% water, with 30 to 45% by volume of air bubbles. Coal additions make the MGD fuels no longer usable as substitutes for natural gas, because they restore the peak heat flux to and above the levels found with oil alone. However, they are of interest for oil-fired combustion equipment, not only because of the economically interesting coal substitution, but also because the thermal efficiency appears to

be enhanced. No field tests have yet been made with coal added to the MGD fuels, but the tests have been conducted with commercial burners.

(End of Abstract)

Captain Flanagan

Thank you, Dr. Shaler. Now, let me introduce our next speaker. He is Dr. D. S. Volkmar, Total, Compagnie Française de Raffinage, and his topic is titled Emulsion Production and Boiler Performance with the Total-Bertin Emulsifier. Dr. Volkmar.

SESSION 3

PAPER 3

EMULSION PRODUCTION AND BOILER
PERFORMANCE WITH THE TOTAL-
BERTIN EMULSIFIER

D. S. VOLKMAR
B. CARRUETTE

Compagnie Française de Raffinage
Paris, France

EMULSION PRODUCTION AND BOILER PERFORMANCE WITH
THE TOTAL-BERTIN EMULSIFIER

D. S. VOLKMAR AND B. CARRUETTE

ABSTRACT

TOTAL-BERTIN emulsifier is a small device without any mechanical moving part, using the self-generated vibration of a metallic diaphragm (U.S. patent No. 3809372). It needs no other energy source than a moderate pressure drop of the fluid itself. Two emulsifiers have been developed for applications covering the range 5 to 1300 l/h emulsions. Median water drop diameters observed for heavy fuel oil and large flow rates, without using any surfactant, are in the range 10 to 20 microns.

In fired combustion application many tests have been run, using our emulsifier. Some emulsifiers are currently in use on industrial boilers and furnaces in France, and operating problems have been solved. It is found that the main effect of emulsion burning is an important reduction in pollutant emissions, with, in most cases, a slight reduction in energy consumption:

- Particulate emission is reduced by 60-80% in the case of residual fuel oil (No. 6 fuel oil) and pressure atomizer; by 50-60% with lighter fuel oil (No. 4 or No. 5 fuel oil). This may allow a large reduction of excess air.

- NO_x emission reduction depends on specific installation. It can be important in some cases.

- SO₃ emissions can be reduced, mainly due to excess air reduction. Of course, vaporization of water needs some heat and reduces the maximum flame temperature. On the other hand, feeding the burner with emulsion 10-15% water results in a better fuel-oil atomization and a better air fuel mixing which makes a decrease of excess air possible, thus leading to cleaner heat-exchange surfaces: these two factors may result in a substantial increase of the overall efficiency.

Cost for the equipment of a 10 t/h existing boiler ($0.75 \text{ m}^3/\text{h}$ of residual oil) with a modulation ratio of 1 : 5 is found to be 2 to 3 French francs per ton of fuel oil, which compares favorably with the cost of using combustion additives.

Our emulsifier is ready for use in boiler application with any fuel oil, from No. 2 to No. 6. We can also offer our technique for other applications.

(End of Abstract)

Captain Flanagan

Well, thanks to Dr. Volkmar, we will have a few minutes for questions or discussions following his paper. In all fairness, since Dr. Volkmar has provided us with this bonus, we ought to accept questions for him first. Please identify yourself.

Dr. Volkmar

Let me add this bit to my previous comments. These units are all experimental; they were made in a machine shop, and they are not production models. Actual production models would not be nearly as massive or heavy as what you see here.

Professor Essenhigh

What is the pressure drop across this system?

Dr. Volkmar

The one I've seen installed on an industrial-size boiler, and the pump was not changed, nor was the control system. The pump put out about 110 psi, between 100 and 110 psi. We pumped to the same burner, and as far as I know the inlet pressure at the burner was in the vicinity of 100 psi.

Captain Flanagan

Dr. Dryer?

Dr. Dryer

Could you tell us what the particle size distribution, the Sauter mean diameter for the internal phase, is?

Dr. Volkmar

I'm sorry I cannot be more specific than to tell you the information sent to me from France, that is, in the 10 to 20 micron range. I think they are giving this further study, and if you wish still further information, you could write to Dr. Carruette.

Captain Flanagan

Any more questions to the previous two speakers?

Dr. Schwartz

Professor Essenhigh, what is the heat release in your unit, and the mean residence time of the gas, assuming some firing rate?

Professor Essenhigh

The furnace is operated at 1.2 million BTU per hour. I can't tell you the residence time, but you can work it out. Its volume is 40 cubic feet.

Dr. Schwartz

What's the approximate temperature profile in those units? I understand that you can vary the flow rate of the heat transfer fluid, whatever you're using, so that you can really program any way you wish.

Professor Essenhigh

Only the tubes, you mean? The tubes are simply water cooled, so we're simply measuring the water flow and the temperature rise.

Dr. Schwartz

How about the gas temperature, now?

Professor Essenhigh

We have not measured the gas temperature. We've got roof temperatures. I don't know if you've done any three-dimensional probing, but it's one of those things that you want to stay away from until you know exactly what you're looking for. Otherwise, you pile up great amounts of data that you don't know how to handle. Actually, we're going to have to do this sooner or later, and there are provisions for it, but we don't have the details.

Dr. Zwillenberg

Would this technique have any application for utility boilers, where a convective section follows the radiant section, and where the efficiency is about 85% to start with?

Professor Essenhigh

You get 85% efficiency because of your convective section. The efficiency in the radiant section is usually about 45% to 50%. You're asking a more complicated question than that, because you must decide what exactly it is you're after. With a utility boiler you're already getting a maximum thermal efficiency merely by having so much heat transfer surface. By the time you finish, you're going to get all the heat out. So, you're not going to use this from the point of view of improving thermal efficiency. As a matter of fact, when we added an emulsion in our firing system, the efficiency went down. With long enough exchange surface, you can bring it back up again. You'll be doing it practically for other purposes such as NO_x control, particulate control, or something like that.

Dr. Shaler

I would add just one comment to that. If you've got a furnace, no. If you're designing a new furnace, probably. If you've got a furnace there's no point in changing, because the gain would certainly not be very great.

Professor Essenhigh

Well, unless it's an add-on for something specific like NO_x control or emissions control, or switch to some other fuel.

Dr. Shaler

Or some less expensive fuel.

Dr. Bastress

I have a question for Professor Essenhigh. Bob, there is a sequence of logic at the beginning of your talk that I fail to follow. Perhaps you can clarify it for me. You indicated that an increase in water with the fuel resulted in a decrease in efficiency and an increase in exhaust temperature. On the basis of those observations you said something to the effect that you cannot attribute the decrease in efficiency to a decrease in flame temperature, that there had to be a change in emissivity. I don't quite follow the logic. It seems very logical to me that the water induces the decrease in flame temperature, and hence a decrease in efficiency. Tell me where we differ.

Professor Essenhigh

First of all, if you look at the amount of water we're adding and calculate the change in adiabatic flame temperature, it's too small. It's an awful small amount. The thermal loading of 10% water is very, very small. But it's not that alone; it's also the fact that the temperature of the gases coming out depends on how much heat comes out in the roof and the walls, and not in the load. So, what we're saying is that, whatever the reason may be, we observe first of all that when the water temperature goes up, less heat is pulled out in the tubes. That is measured directly. This means that the heat has to be transferred to the tubes. It comes from the flame, from the roof, and walls. When we look at the roof and the wall temperatures, we note that they also have dropped. So, not only has the heat transfer from the flame dropped, but the heat transfer from the roof and the walls has also dropped. This also corresponds to a reduced heat transfer through the walls. So, with more heat coming out in the load,

less comes out in the walls, and the balance has to come out in the stack. The temperature therefore goes up to compensate, and the heat balances substantiate that the wall losses have also dropped.

Now you are aware that the expression for heat transfer is hard to integrate directly. However, the approximate expression for heat transfer is $\epsilon \Sigma (T_{\text{flame}}^4 - T_{\text{tube}}^4)$. Therefore, if the total heat transfer remains the same and heat has been transferred to the tubes, as already noted, then the flame temperature must have gone up also.

Dr. Bastress

The gas temperatures have gone up?

Professor Essenhight

Gas temperatures have gone up because you are taking less heat out from them.

Dr. Bastress

What about the exit gas?

Professor Essenhight

The exit gas temperatures have gone up, but all profiles have gone up.

Captain Flanagan

In fairness to our next speaker, we are going to move on. Please save any additional questions for the discussion period after the next coffee break.

The next speaker is Mr. R. R. Kinney of the Gaulin Corporation. His topic is titled Discussion of Test Results with Boilers and Gas Turbines. Mr. Kinney.

SESSION 3

PAPER 4

DISCUSSION OF TEST RESULTS WITH
BOILERS AND GAS TURBINES

RICHARD R. KINNEY
Gaulin Corporation
Everett, MA

DISCUSSION OF TEST RESULTS WITH BOILERS AND GAS TURBINES

RICHARD R. KINNEY

ABSTRACT

Over the last five years we have undertaken a series of test programs. Our first efforts involved blast furnaces, where the objective was to substitute heavy oil, i.e., cheaper BTUs, for metallurgical coke. Due to poor atomization, carbon emissions were excessive. A water-in-oil emulsion improved secondary atomization and doubled the quantity of oil which could be injected.

Evaluations were made on gas turbines, both for smoke reduction and burning of heavy fuel in lieu of distillate. Seaworthy Engines of Connecticut installed a system on Seatrain's Asialiner. The objective was to determine if water-in-oil emulsions would improve secondary atomization of a blended residual/MGT, enabling the cheaper fuel to be burned effectively. Using centrifuging, inhibiting, and a 6% water-in-oil emulsion in a Gaulin homogenizer, the residual blend is being burned at a saving of \$20/ton to \$30/ton.

Combustor rig tests indicate that water/JP5 emulsions (stabilized with an additive) reduce carbon emissions up to 50%. Full scale tests are now underway.

Also evaluated were several large, industrial boilers (100,000#/hr.). Where minimum excess air (no emulsion) is above 20%, there is latitude for improved efficiency with emulsions. Tests showed that if minimum excess air is 30% or over, and with a reduction in carbon emissions, a reduction in excess air is achieved, more than offsetting the BTUs required for water vaporization.

This leads to applications where carbon emissions per se are a problem, and a water/oil emulsion can alleviate, and perhaps resolve, such problems without an adverse effect on boiler efficiency.

We are involved with a program evaluating coal-in-water/oil slurry. The emulsion appears to enhance coal slurry stability, and may provide benefits associated with micro-explosions.

(End of Abstract)

Captain Flanagan

Thank you, Mr. Kinney. We will save our questions for Mr. Kinney until the general discussion period. Now we will continue with the next speaker, Dr. C. A. Moses, of Southwest Research Institute. Dr. Moses' subject is titled The Use of Fuel Emulsions to Control Exhaust Smoke from Jet Engine Test Cells. Dr. Moses.

SESSION 3

PAPER 5

THE USE OF FUEL EMULSIONS TO
CONTROL EXHAUST SMOKE FROM
JET ENGINE TEST CELLS

CLIFFORD A. MOSES

Southwest Research Institute
San Antonio, TX

THE USE OF FUEL EMULSIONS TO CONTROL EXHAUST SMOKE FROM JET ENGINE TEST CELLS

CLIFFORD A. MOSES

ABSTRACT

Low-internal-phase-ratio emulsions of water-in-fuel have been investigated for their potential in reducing exhaust smoke from gas turbine engines. The specific application that this project addresses is for a reduction in the plume visibility from engine test cells at Naval Air Rework Facilities where an engine hardware change is not possible. Results from combustor-rig tests and a recent full-scale engine test are presented.

The combustor experiments were conducted with a combustor rig fabricated from Allison T-63 engine hardware. The fuel was a typical JP-5 Navy jet fuel. Continuous decreases in exhaust smoke were observed up to the highest concentration tested, a 0.5 water-to-fuel ratio. The maximum reduction in exhaust particulate concentration was 80 percent, based upon a correlation with the Smoke Number. Concentrations of 15% and 30% water were tested over the T-63 power spectrum, and smoke reductions were observed at all power points. The greatest reductions were found at the highest power points, where the smoke problem is the greatest. Measurements of gaseous exhaust emissions were also obtained. NO_x was reduced by increases in water concentration, with the greatest reductions occurring at the higher power levels. CO and unburned hydrocarbons increased with water concentration; the increases were small at full power, but became increasingly large at the lower power conditions. The increases in CO are related to the lowering of the primary zone temperature, and hence the CO and CO_2 oxidation rates. The increases in UBHC are related to the increase in fuel viscosity when water is added; the viscosity increase causes a larger SMD of the spray and longer evaporation times. At high power conditions, the secondary atomization processes are strong enough to counteract the effects of the larger drops; at lower

power, the flame temperatures are lower and the secondary atomization processes less effective. Combustion efficiency was calculated from the exhaust chemistry, and always decreased with the addition of water. The reductions in efficiency were very small at full power, but became quite significant at the lower power conditions.

The full-scale engine tests were conducted with a J-79 engine at the naval facilities in Trenton, NJ, to determine the effects of emulsified fuel on engine performance and operation and on reduction in exhaust plume visibility from the test cell. Also included was a test of the fuel-control system to look for deleterious effects caused by residual water. The test schedule, consisting of five cycles of approximately two hours at full power followed by a 22-hour soak, was established to simulate the performance proof-testing an engine might experience at a rebuild facility.

(End of Abstract)

Captain Flanagan

This concludes the presentations for today. We will have a discussion after the coffee break. Are there any questions for the last speaker? Yes, sir.

Dr. Bastress

I'm quite interested in your control of smoke, but I'm also extremely impressed by the control of NO_x , achieving a 50% reduction at full power in NO_x with 30% water. This combination seems to provide far better performance than others, and I urge you to pursue it to see whether perhaps you have come across a significant test result.

Dr. Moses

Is your question related to typical emulsions, or to water injected into the primaries?

Dr. Bastress

Yes, water injected into the primaries.

Dr. Moses

I think one thing this gives us is that it puts the water where it does the most good in reducing temperatures in the fuel-rich zone right in front of the nozzle, and in the fuel rich core. In this case we are inserting fuel intimately close, whereas with some of the water injection techniques the same result is not achieved.

Dr. Bastress

Thank you.

Captain Flanagan

I think we're going to find similar NO_x reductions in diesel presentations tomorrow. Mr. Winkler.

Mr. Winkler

In response to your question about NO_x reduction through emulsions, we've seen the same thing on a different engine, a real gas turbine. We try to place the action where the NO_x generation is. Mixture of water in the fuel and the total reaction with water, fuel, and air are critical in the very early stages of combustion. If you don't provide the proper initial mixture, the water will have been wasted. That's the reason for putting the water at the inlet of the engine. When mixed totally with air, it's useless. Thus, emulsion is a very effective tool. We've seen numbers on the same order as those of Dr. Moses.

Captain Flanagan

The characteristics of the emulsion may be very important. Some experimentation on NO_x was performed at Research Triangle Park by EPA, in which the emulsor was nothing more than a gear pump. This resulted in very little improvement. The question is, did they have an emulsion? We don't know.

Dr. Dryer

In the research to which you refer, the investigators found quite an amount of fuel nitrogen in the system. What we're talking

about here is thermal NO_x reduction. Henry Shaw, of Exxon, has published a paper in ASME, Winter Annual, 1975, in which he correlated the amount of water added to the primary zone with the amount of NO_x reduction. You can, indeed, get almost the same reduction of NO_x with the addition of 30% water if you put it all in the primary zone. However, something very interesting has been overlooked. Certain work performed at General Electric has shown that the addition to a system of from 10% to 12% steam not only serves effectively as a means of NO_x reduction, but also increases the cycle efficiency of gas turbines by almost 20 to 30%. It is conceivable, in fact, that the addition of steam to recycle heating in the exhaust system combined with direct injection of water into the primary zone can more than compensate for the price paid in terms of high-purity water necessary for NO_x reduction in gas turbines.

Captain Flanagan

That's an interesting concept. Yes, sir.

Dr. Zwillenberg

I notice that even with no water addition, the NO_x figures are quite low, actually lower than the emission standards proposed by EPA. If you could meet the EPA emission standards without getting involved with water mixtures, why were you worried at all about the NO_x content?

Dr. Moses

This is one particular combustor which happens to meet the standards. The engine itself is only about a 250- or 300-horsepower engine. It's not a problem with that engine; it just shows that you can reduce NO_x .

Dr. Zwillenberg

That you can reduce NO_x . Thank you.

Captain Flanagan

What is the EPA requirement for NO_x ? Is it 75 ppm as proposed?

Dr. Zwillenberg

It's 75 ppm at 15% O₂.

Captain Flanagan

Thank you.

Mr. White

Did you make any attempt to measure emulsion stability? You seem to draw the conclusion that because you've increased the amount of surfactant, you have a more stable emulsion. But, in fact, if you add more surfactant, you may have had the same amount of stability but smaller droplet sizes.

Dr. Moses

Looking at it strictly from a beaker standpoint, I agree with your statement. As for the amount of surfactant, it took better than 1% of surfactant to have what appeared to be a reasonably visible stable emulsion without dramatic creaming, just separation. We did do some work with the microscope; some photomicrographs are included in the paper. We also varied the drop size. One of our reasons for choosing the Gaulin system was that we could vary the energy that we were putting into it, and that, thereby, we could change the dispersion size and the characteristic of the emulsion. Within the range over which we could operate, this did not affect the smoke reduction potential of the soot. However, the range that we could operate over, 1 to 10 microns, is still very small compared to the drop size in the spray, which is in the vicinity of 80 microns. So, it is reasonable to expect that there wouldn't be much of an emulsion in that range.

Captain Flanagan

I have one quick question. You say your percentages are by volume. Do you calculate your percentage as water over water plus fuel volume?

Dr. Moses

It was done both ways.

Captain Flanagan

What you gave us, then, was the latter calculation, say, 50% by volume?

Dr. Moses

Let's say 33 1/3 percent by volume, that is, one part water and two parts fuel.

Captain Flanagan

Actually, as I see it, the data were reported both ways. Not only do we have data by volume and by weight, but even the method of calculating the percentage is different.

Dr. Moses

The data appeared on the graphs in two ways. One applies to a water-to-fuel ratio. For example, on this basis, a fifty-percent ratio would refer to one part water and two parts fuel.

Captain Flanagan

And how about a water-to-emulsion ratio?

Dr. Moses

On a water-to-emulsion ratio, it's one-third. That is, water constitutes one-third of the emulsion.

Captain Flanagan

All right. With that let us indulge in a coffee break, and then continue with our discussion period.

DISCUSSION PERIOD

Captain Flanagan

We will open this discussion period with an invitation for pertinent questions from the general audience for any of our presenters. Before we begin, I wish to announce that a couple of our presenters have had to leave. A few individuals have directed questions to them in writing. The presenters have either answered the individuals, or will call them as soon as possible and talk to

them. The questions that I saw were not of general interest, but were on rather specific items of interest to those particular individuals. I don't think that the group has lost a great deal in this respect. Let us begin, then. Yes, sir.

Dr. Peterson

I have a question, but I don't know to whom to address it.

Captain Flanagan

All right, go ahead and ask anyway, and I'll see what I can do. Go on.

Dr. Peterson

Maybe Mr. Kinney of Gaulin could answer this one. Last August, the sixteenth Symposium on Combustion was held at MIT. At one of the discussion sessions, the comment was made that when water was added to a gas turbine burner, the NO_x contribution from the fuel bound nitrogen increased, suggesting some change in kinetics. In some of these other fuels - lower-grade fuels - quite frequently the nitrogen concentration's a good deal higher than in cleaner fuels. It is possible that water addition might increase the nitric oxide emissions?

Mr. Kinney

Are you talking about gas turbines specifically?

Dr. Peterson

Yes.

Mr. Kinney

Well, I believe that in all cases fuel nitrogen is extremely low compared to the air nitrogen source. I think that Matt Winkler may be in a better position to answer that. As far as change is concerned, I would expect that with fuel nitrogen you've not going to have any effect with an emulsion, and that the only effect would be on air nitrogen. I would also expect that fuel nitrogen conversion can be affected in ways pretty much unrelated to emulsion or to percent water in emulsion form.

Dr. Peterson

Now, that was the point. The statement actually made was that water changes the conversion rate of the fuel-bound nitrogen by somehow changing the kinetics. Daniel Moore from General Electric made this statement.

Captain Flanagan

Matt Winkler is from Seaworthy and works not exclusively, but certainly a great deal, with fuel systems, particularly gas turbines and boilers. Do you have anything to add, Matt?

Mr. Winkler

I agree in general with Dick's comments from my past observations. The primary burden you're dealing with is thermally generated NO_x , not fuel-bound NO_x and water emulsions. Water, in general, and emulsions, in particular, are so effective in controlling that aspect of it, that the argument in its favor is overwhelming. I don't know specifically the answer to your question, as there are subtle differences in the reaction rates of fuel. However, I assume from what I have seen that the results are overwhelming in the direction that I have indicated.

Captain Flanagan

I have a question relative to the Navy test facilities, on the problem of smoke. The addition of surfactants was necessary to reduce smoke in these particular tests. You were using JP 5. Correct? JP 5 is a distillate fuel which, according to the discussion by Dr. Law about the possibility of a micro-explosion, has a threshold of pressure below which micro-explosion will not occur. It is possible, then, in the case of this combustion can and this aircraft engine, that you did not have micro-explosion at all? What kind of pressures were in that combustion-can?

Dr. Moses

At full pressure you operate at pressures in the neighborhood of five atmospheres.

Captain Flanagan

Does that apply to JP 5?

Dr. Moses

Yes, a little under five atmospheres.

Dr. Dryer

The end boiling point for JP 5 is about the temperature with which you're concerned.

Dr. Moses

About 500 to 530 degrees Fahrenheit.

Dr. Dryer

The important point there is that micro-explosion or secondary atomization may not occur very early in the droplet lifetime. However, very early in the droplet lifetime is not the time during which liquid phase heterogeneous formations of carbon particles are very important. It turns out that in the later lifetime of the droplets, in most cases, the droplet temperatures get very close to, if not beyond, the levels of nucleate vaporization. Also, the number of levels that Ted Wald showed you are about 20 to 40 degrees higher than those produced through the kinetic theory.

A paper soon to be published from Princeton will cover the complete theoretical kinetic development for predictions of nucleate boiling temperature and emulsion structures. We have compared the analytical results from that theoretical model with our own experiments, and we find agreement within one or two degrees of the statistical upper limits of nucleate vaporization. That is not to say, however, that vaporization will not occur below that limit when contaminants in fuel are taken into account.

Captain Flanagan

It is correct that it's necessary, in this particular case, to have a micro-explosion for NO_x reduction anyway?

Dr. Dryer

Absolutely.

Captain Flanagan

For smoke reduction it's probably necessary, and it probably did happen in this application. Is this generally agreed?

Anonymous

No, it's not agreed upon. It's not clear whether it's kinetic or another action.

Dr. Law

It's cooler because of the addition of water in the vaporization process.

Captain Flanagan

Right, so that takes care of the NO_x .

Dr. Law

No. That takes care of the liquid phase or pyrolysis.

Dr. Moses

It is my opinion, and perhaps Matt's, that in distillate fuels in this boiling range, the liquid-soot kinetics formation of cenospheres is not the important phenomenon for soot formation in primary zones, mainly because of gas-phase kinetic reactions that take place, leaving a lot of soot behind. Primarily, it's dominated by the presence of aromatics in the fuel which are easily stripped of their hydrogen. But the carbon ring is quite stable, and aromatics are relatively stable when compared with paraffins. At the same time, however, in the kinetics that ensues, if it occurs round the droplet, or if it's in the bulk or in a sheet flame around a lot of droplets, the presence of water does affect the reaction kinetics. Increases in the presence of water will drive the reactions away from the presence of free carbon. So, although it's not clear whether or not that happens, there is a possibility that it does affect the kinetics in the gas-phase reaction. It's also not clear whether the micro-explosions do, in

fact, take place. There have not been any base experiments which show that this takes place in a typical fuel spray, in a typical turbine combustion cell. However, if it does take place, the phenomena that go on would appear to contribute to the reduction of soot formation. In one instance you have the formation of smaller fuel droplets which will vaporize earlier. Another important consideration is that initially all these fuel drops have a directed motion, in one direction, as they come out of the atomizer. If micro-explosions take place, we now have a mechanism for sending small drops of fuel perpendicular to the original directed motion. This will increase the air/fuel mixing process, which has a very drastic effect on soot reduction.

Captain Flanagan

Then there is the heavier fuel case.

Dr. Moses

In a heavy fuel case the liquid-phase reactions are dominant.

Captain Flanagan

Dr. Dryer, you have a comment.

Dr. Dryer

I don't see how you can discount cenospheric formations in gas turbines or in diesels. It turns out that the droplet size distribution in those cases is so small that, if liquid-phase heterogeneous reactions occur, the particle sizes formed are going to be very close to those that are formed in the gas phases. The only reason you can distinguish between liquid-phase heterogeneous soot in boilers from gas-phase soot in boilers is that the particles are so big in the atomization process that the liquid-heterogeneous process leads to a very big soot particle. In the case of diesels, or of gas turbines, it is going to lead to the same size particles, and the particle-size distribution analysis is not going to provide the distinction.

Dr. Moses

It's not only the particle-size distribution, but also the structure of particles, which tend to be hexagonal platelets that are built up.

Dr. Dryer

No one has been able to prove that that doesn't happen in the liquid-phase.

Dr. Moses

I think it's more likely to occur in the nucleation in the gas-phase reactions at these rates than for the hydrogen to be stripped off of aromatic rings that are still in the liquid phase.

Dr. Dryer

You have substantiating data for that?

Dr. Moses

Emerich and Phillips have done photoelectron micrographs of the soot particles in the exhaust as functions of the fuel type, fuel characteristics, and the like.

Dr. Dryer

Can you be more specific? Do you have substantiating data indicating that the same process does not occur in the liquid-phase?

Dr. Moses

There is none.

Captain Flanagan

Yes, sir.

Dr. Shaler

I think the trouble is that we're making comparisons between completely different things. Dr. Moses' unit is operating in the vicinity of 1,000% excess air, while the rest of us have been talking about 10% to 12% excess air. The whole chemical

sequence is very different. I would be willing to go along with Dr. Moses' explanation that this has to do with the fuel, and particularly the aromatics. It's not at all the same problem as smoke related to fuel oil, utilities, gas, and radiant tubes.

Dr. Dryer

In terms of the soot-formation mechanism, it's not different. You are still running the primary zone very nearly stoichiometric, not much excess air at all. It's only an overall excess air.

Dr. Moses

This primary zone is very close to stoichiometric. It's more fuel-rich. If anything, it's fuel-rich, especially in the core around it. It's not uniform. The soot formation takes place in the fuel-rich core, in front of the fuel nozzle.

Captain Flanagan

Are there any more questions? Yes, sir.

Dr. Murayama

I would like to know about the possibility of soot reduction due to the water-gas reaction, which we know as $C+H_2O \rightarrow CO+H_2$.

Dr. Dryer

It has been suggested many times that the water-gas reaction is a mechanism through which soot reduction occurs. However, there has recently been some work done in France by Fugay suggesting that the reduction is not related to the water-gas reaction. Fugay relates the reduction to the substantial increase in hydroxyl-radical concentrations in the fuel-rich region of the combustion zone, where oxidization occurs at a more rapid rate than in the precursor species which finally polymerizes and nucleates to form carbon. This work concludes that the addition of metal particle materials increases the reaction rate of hydrogen atoms and water, and forms hydroxyl. The same thing occurs in putting water in an emulsion structure, bringing up the old adage: "We've got a pound of water for every pound of fuel

burned; why do we need to add more?" The answer is we need to add more because we're adding it in a fuel-rich region. And, by adding it in the fuel-rich region, we're putting water where it can react with high concentrations of H atoms and produce hydroxyls.

Captain Flanagan

Thank you. Yes, sir.

Dr. Tuteja

I would like Dr. Dryer to elaborate somewhat on the soot precursor to which he referred in his discussion of Fugay's findings.

Dr. Dryer

The soot precursor analysis is probably the most wide-open field in combustion research that can currently be considered in terms of soot-formation mechanisms. Every one has been dealing in the area of nucleation for controlling soot formation. I feel that we can't do much about nucleation processes. There are just too many ions, and there are too many radicals in combustion systems to do very much in terms of controlling the number of nucleation sites. What we can do is decrease the concentration of precursor species through oxidation, and not through additional reactions. By doing that, we lower the polymerization rate; a lower polymerization rate enables us to lower the nucleation rate. This is an area of current interest in our own laboratory, as well as in a number of other laboratories. I don't believe that there is any available information as to what these precursor species look like.

Captain Flanagan

I am interested in putting together a list of topics for research. I hope that in our last discussion session tomorrow you will help me formulate those areas of research from which we can all benefit. For example, we might wish to investigate the significance of on-line real-time droplet size distribution, or

perhaps to study the precursor of soot formation. Another example, though more pertinent to me, indicates the direction our investigations could take. The United States Navy currently uses distillate fuel, which costs four times as much as bunker C and three times as much as NSFO, just to keep the fire sides of Navy boilers clean. There must be a cheaper way to do this. If I can get the consensus of the group, we will add this to our discussions and recommendations. I'm quite confident that I can then have people in high places transmit this information where needed, with recommendations for research that would help our energy program.

Mr. Winkler

You mentioned keeping fire sides clean on Navy boilers, switching from NSFO to distillate fuel. Most of our experience of late has been in the area of gas turbines, both General Electric and the Pratt and Whitney units. We have observed that generally, when emulsions are fired on residual oil systems, the turbines are cleaner than when standard distillates are fired without emulsions.

Captain Flanagan

Well, we could ask them about this.

Mr. Winkler

Aside from that, if you have ash buildup because of the ash that's in the residual oil, plus the additives that you put in to inhibit the vanadium, there is buildup and fouling on the turbines. However, it's not from carbon, since it is distillate that's being fired. With most distillate turbines, when you get to work around with them very much, you get pretty dirty. No so with these engines.

Captain Flanagan

You appear to have other problems.

Mr. Winkler

That may be a misnomer, but the fact is that in two cases that we know of, both of which have accumulated many thousands of operating hours, that's the case.

Captain Flanagan

I'm asking the group again to think of more ideas of the type we have just brought up. Please jot them down, and we'll tackle them tomorrow.

I believe some researchers are going to indicate that it is possible to foul up a good emulsion burning system by adding a chemical surfactant. We've heard just the opposite today, so I hope we can get to the bottom of that. Yes sir.

Mr. Ballard

Has anyone done anything with the addition of water on flue-gas and dewpoints in the formation of acid? What is the effect of adding water?

Captain Flanagan

From a corrosion standpoint?

Mr. Ballard

Yes.

Captain Flanagan

I do not know. Mr. Wilson, from ADL, may know. He worked in this area, and he was here earlier today, but I don't see him now. Yes, sir. Jim?

Mr. White

In a recent issue of Chemical Engineering, a McGraw-Hill publication, there's an article on the effect of various constituents in flue-gas on the dewpoints for condensing sulphuric acid. That may be of help.

Captain Flanagan

Does this include burning of emulsions?

Mr. White

No, it's just a general discussion of combustion of different things, and of when you can expect to have a lot of acid come out of the flues. So you'd have to look at what the emulsion was, and

what it contained, and, if you burned it, to make some judgments on the results. For example, if you get a very small amount of sulfur trioxide, you can expect that it will have quite an effect on everything.

Captain Flanagan

I would like to know if anyone here has had experience in burning emulsions in boilers, and if so, whether he has experienced corrosion problems on the tubes or uptakes. Has anyone here been associated with the burning of emulsions in boilers for periods sufficiently long to permit detection of such corrosion problems?

Mr. Kinney

On the Trans-Indiana, which has been running about eight months, they've inspected the boiler at least twice, I believe, with no indication of corrosion problems.

I'm familiar with that Chemical Engineering article that Jim White referred to. Calculation included in that article indicates that with the addition of five percent water to the known water from combustion, the dewpoint temperature is affected. I read the article very quickly and haven't had a chance to review it, but as I remember, the temperature decreases by 10 to 15 degrees. Actually, the five percent water addition represents a relatively small change; it goes from one pound per pound of fuel to 1.05 pounds per pound of fuel.

Mr. White

Well, I don't think that the addition of water is the chief factor in the effect noted. You'd have to look at the surfactant.

Mr. Kinney

We're talking about boilers. We have done nothing with No. 2 fuels or with surfactants.

Captain Flanagan

That's my next question. What kind of fuel is being burned in this boiler?

Mr. Kinney

No. 6 fuel.

Captain Flanagan

No. 6 fuel? This has natural surfactants, as you know, so there is no addition involved.

Mr. Kinney

Yes, sir. The only work that's been done with the surfactants being added is on No. 2 or a jet fuel, where it is apparently unstable. You have to have a chemical additive to build stability, or at least to ensure stability for this test program. Another case in point: if you run a boiler with emulsions and cut the excess air, you tend to reduce your SO_3 formation. Not very much, because you've got a catalyzed reaction, but directionally at least. If you tend to reduce the excess air, you should reduce the SO_3 .

Captain Flanagan

Now, let's not forget what the gentleman's original question was. He's interested in changes in dewpoint, increased corrosion problems, etc., on tubes and uptakes, correct?

Mr. Ballard

Yes, sir.

Captain Flanagan

Now I can start pointing to people who want to speak on that in further detail. Matt Winkler.

Mr. Winkler

I can't answer your question directly, because we haven't as yet got the answer in our testing. One of the test objectives of the MARAD Program, in which six steamships are operational, and one of them through use of emulsified fuels, will be the investigation of cold-end deposits and cold-end corrosion. The ship has not run long enough to provide an answer to that question, but the answer will be forthcoming in due time. Secondly, I think a

lot of the problems that we have seen, in the uptakes of marine boilers in particular, have to do with a high concentration of carbon solids. Much of the sulphurous-type materials condenses on the carbon particles and creates problems there. We're hopeful, from what we've initially seen, that the results of the emulsion firing will cut the carbon loading to such a significant degree that the effects of these slight depressions in the dew-point will be reduced. They won't manifest themselves as deposits, and hence additional corrosion.

Captain Flanagan

But, from a testing standpoint, that's conjecture.

Mr. Winkler

The data are being generated right now. They're just not available at present.

Captain Flanagan

Dr. Volkmar.

Dr. Volkmar

Some of the information in the paper I gave is based on tests that are now being conducted with Electricity du France, a French utility where they're burning No. 6 fuel with water emulsion and no surfactants. They claim a considerable reduction in particulates, mostly because the carbon is all burned up, with resulting reduction in SO_3 , which has already been mentioned. That's about all I can say about it. I hope that Electricity du France will provide details on it sometime soon.

Captain Flanagan

I have a comment to make. If someone feels that I'm technically wrong, please speak up and prove your point. Crude oil No. 6, Bunker C, Navy special, these heavier fuels all have surfactants in them by their nature, so that it usually is not necessary to obtain stability by addition of chemical surfactants. Does anyone wish to rebut this?

Mr. Winkler

No, I actually want to support it. The lightest marine fuel that's presently being made available in ports is 200 Redwood-second oil, which is the highest dilution with distillate. In emulsions that we've made in our gas-turbine test ships, we can see essentially no separation of the emulsion after a year.

Captain Flanagan

After a year? Sounds impressive.

Mr. Winkler

And that's with no additional surfactants. It's with the lightest concentration of surfactant because of the highest dilution rating.

Captain Flanagan

You refer to no additional surfactants. But when you get into the distillate fuels like the clean diesels, the JPs, and other clean fuels, you'll note that they're clean enough so that very little, or no, surfactants are there. Dr. Dryer?

Dr. Dryer

I'd like to corroborate Matt Winkler's comment. But now I want to bring up something else, namely, that we start to talk about coal-derived, or shale-oil-derived fuels. The aromatic content of these materials goes up. It appears that the surfactant level of these materials is more commensurate with the formation of fuel-in-water emulsions than it is with water-in-oil emulsions. One finds that with multi-phasing or the structure of oil in water, the phase of the oil becomes a very significant problem.

Captain Flanagan

Oh, you're speaking specifically of coal-derived and shale-derived oil.

Dr. Dryer

I'm speaking specifically of the fuels that have increased aromatic content. Sooner or later we'll be concerned with the control of the aromatic contents.

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TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MASS F/G 21/4
PROCEEDINGS OF SYMPOSIUM ON WATER-IN-FUEL EMULSIONS IN COMBUSTION--ETC(U)
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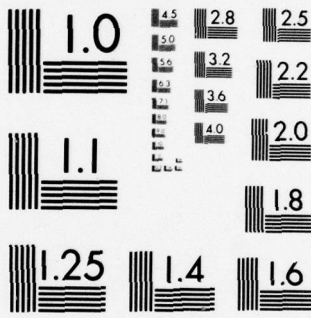
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Captain Flanagan

Very interesting exception, one that will undoubtedly continue to give concern.

Mr. Winkler

In the same area we have found that, generally, if you have 25% by volume or greater of a residual heavy oil blended into a distillate, you will have enough natural surfactant to obtain a stable emulsion at relatively low-percent water. We've been working at a level under 10%. The second problem you will have is that if you have a highly paraffinic heavy oil, you will tend to have a relatively poor emulsion. Asphalt-based heavy oils are excellent; paraffinic oils are marginal, even though they are redisuals.

Captain Flanagan

As a matter of fact, I'd say that Dr. Little even uses NSFO as if it were a surfactant.

Mr. White

I'd like to make one comment about corrosion. Dr. Walter Boyd, of Battelle Columbus, is, in my opinion, one of the most knowledgeable men in the country in the study of the effects of corrosion on boilers and incinerators. Perhaps, if you get in touch with him, he will help answer your questions regarding the potential effects of emulsions.

Captain Flanagan

All right, now. Any new questions?

Professor Fogler

Yes. It has been shown that you can form mists with application of acoustics. You can have fairly controlled particle size. I wonder if people have looked at the possibility of using this concept on burners. I know that some work was done on it a while back. It was looked at briefly by Young at Esso. But I wonder if anyone else has thought of atomizing and controlling the particle

size by controlling the frequency to get very uniform particles, and therefore, very uniform burning.

Captain Flanagan

I don't know.

Professor Fogler

Is there any reason why it might be unfeasible?

Captain Flanagan

Do you have a comment, Dr. Dryer?

Dr. Dryer

Yes. The very uniform particles that you talked about are about 200 microns in size. Am I correct?

Professor Fogler

That's at one frequency. Actually, the size of the particle varies, at the higher frequencies, inversely with frequency to the two-thirds power.

Captain Flanagan

Can you get down to one micron?

Dr. Dryer

Can you get 10 microns?

Professor Fogler

Yes, 10 microns. It depends on the properties of the fluid you're atomizing. I think that 200 microns corresponds to about 100 kHz. But there are currently available generators that could easily go up to 1 MHz.

Captain Flanagan

What is their power efficiency?

Professor Fogler

I'm not aware that anyone has measured the efficiency. I think that in the emulsification process we have calculated an

efficiency of about 40 percent in terms of cavitating surface, but that's as far as we've gone.

Captain Flanagan

Has anyone tried to use acoustically produced fine and atomized material for a uniform droplet size in the combustion process?

Dr. Shaler

The Pennsylvania State Government asked us that same question. Professor Essenhigh and I calculated it, and found it uneconomical to go to the ultrasonic range, even with the 40 percent figure you quoted, which is slightly higher than the figure we arrived at.

Captain Flanagan

Yes, sir.

Mr. Romanik

What droplet size? You mentioned a figure that could possibly go under 10 microns. All right. Now, Dr. Shaler, what droplet size were you looking at as atomizing with a mechanical emulsifying device?

Dr. Shaler

Fifty. Thirty to eight-micron size.

Mr. Romanik

Okay. Why ten microns?

Dr. Dryer

Well, if you go back and look at the work of Burgoyne and Cohen, published back in the mid-fifties, you'll find that you have to get droplet sizes on the order of 10 to 20 microns before you can burn essentially as a pre-mixed flame. What happens in the case of 10- to 20-micron droplets is that they completely pre-vaporize in the passage through the flame front.

Mr. Romanik

Then you're not talking about emulsions.

Dr. Dryer

He wasn't talking about emulsions.

Captain Flanagan

The discussions of the last twelve minutes have not included emulsions.

Dr. Dryer

In terms of emulsions, I do believe that you can get down much below 10 microns, or on the order of 1 to 3 microns, depending upon your primary atomization size, if for no other reason than for water conservation. And I personally believe that's the significant difference between working at 20% water, or 30% water, or 6% water.

Captain Flanagan

Dr. Dryer, I'll be as direct with you as you have been with us. What experimental basis do you have to say that you need below 10 microns for burning an emulsion?

Dr. Dryer

If you correlate the percentage of water in which you look at the carbon particulate reduction, you will find that the better the emulsifiers, the lower and narrower your size distribution is, and the less water you need.

Captain Flanagan

Down to the sub-microns?

Dr. Dryer

Down to the micron level.

Captain Flanagan

Just down to microns? The smaller that particle, the higher the internal pressure due to the interfacial tension, right? Can you get it so small that a micro-explosion won't occur due to the interfacial tension pressure?

Dr. Dryer

Interfacial tension pressure is not that severe until you get very far below the micron range.

Dr. Law

When you get below one micron, then you start to worry about it.

Anonymous

Now, you're talking about one micron as what, a minimum?

Dr. Dryer

On this matter of range coverage, let me rather give you my considered opinion of the whole problem.

Captain Flanagan

This is a considered opinion.

Dr. Dryer

Yes, and based on considerable critical analysis of what is available, not just in the fundamental areas, but in the practical combustion field. It looks to me as though one can make some general conclusions about what can be done with emulsions for any one practical combustion device. If, however, you are to get specific conclusions about economic and technical viability, then it appears as though you have to do it almost by specific application for different types of units. In line with this, two things that have to be considered are the internal phase size and size distribution, that means that one has to be able to control them. To me that turns out to be a very important property of the kind of emulsifier one is going to pick in terms of use on various devices. I have to be able to determine how much I can vary the particle size or the particle size distribution. In my opinion you want to get very narrow size distribution over all cases.

Captain Flanagan

It's interesting to note how little material is available in the literature on particle-distribution data. It seems that not

more than one article in ten provides such data. The reason, I think, is that it is extremely difficult to do.

There are some techniques available, though. I hope that in the discussions that follow tomorrow, some of the works that Dr. Dryer's doing at Princeton with a device that does do this on-line in real time will be examined and clarified.

Dr. Dryer

There are some fundamental results on hand. There are also some results that I interpret differently than does Dr. Moses in his tests which, I believe, show that internal-phase particle size is a factor in what can be done with emulsions, and that the size range extends down in the order of microns, depending upon what the primary atomization is.

Anonymous

Dr. Dryer, we both know that if, during a program, we come up with some arbitrary data, we somehow have to account for them. Now, for instance, what will be the relative cost in making 5- to 10-micron water droplets and getting them ultrasonically with primary atomization at 30 to 80 microns, as opposed to getting everything from one to one-and-a-half microns and getting them in oil droplets that are three to five microns? Where do you stop?

Dr. Dryer

There are some devices and also some emulsifying systems, not those that have been discussed today, that give very narrow particle size distribution, one micron or so, that are very low-energy-intensive systems, if low is what you're buying in terms of 30 to 80 microns.

Captain Flanagan

We'll probably hear about some of them tomorrow. There are a number of emulsors on the market, or rather a number of them in the patent office.

Dr. Dryer

I would like to ask Dr. Shaler a question.

Captain Flanagan

All right, go ahead.

Dr. Dryer

Dr. Shaler has suggested that emulsions might be a way of replacing gas-fired applications. I wonder how much has been considered in terms of economics relative to blue-flame burners and relative to a system, recently marketed by Allied Chemical, which is characterized by free vaporization of distillates, and which, they claim, is a blue-flame system much like natural gas.

Dr. Shaler

There isn't a radiant furnace equipped with blue-flame burners. I don't know why not. They are ahead of me in this, and yet, I don't know what's holding them up.

Dr. Schwartz

May I address that?

Captain Flanagan

Go ahead.

Dr. Schwartz

I was anticipating a question such as this. The whole question of what you can do in terms of substituting for natural gas has always been a very difficult one. In terms of process applications, process heaters, and industrial boilers, radiant heat transfer is very important. It's a very difficult problem if you're going to attack it by emulsion. If you change the emissivity and the radiation characteristics of the flames, you will demonstrably change the operational behavior of those units. I'm not convinced, in looking at both the Allied Chemical approach and at emulsified fuels, that you can do that in existing process units. Serious problems exist; for example, there is no way you can burn coal in process units without gasifying it or liquefying it before

combustion. There may not be any way of substituting for natural gas, even by going to a very good emulsifier system. It's something that will have to be looked at. Now, I had a call from a gentleman at our Deer Park refinery a couple of weeks ago. After seeing the Applied Chemical system, he said, first of all, that he did not want to change the burners. If you buy emulsified fuel, you have to change the burners.

Captain Flanagan

No, not necessarily.

Dr. Schwartz

You still have to. Let me put this in the form of a question. If you went to the No. 2 emulsified system, which is currently operating on steam atomization, would you require continued atomization if you emulsified?

Captain Flanagan

I don't know.

Dr. Schwartz

Then there's a significant economic incentive to investigating it.

Captain Flanagan

We could possibly control the droplet size distribution, or do something about the right water-to-emulsion percentage. We don't really know. Yes, sir.

Mr. Ballard

I feel that steam atomization is almost impractical, in a sense. There's too much steam at low loads, and just about none at full loads.

Captain Flanagan

Well, I think that the application you were talking about began with steam atomization.

Dr. Schwartz

The units are currently operated with steam atomization. The question put to me by the gentleman at the refinery had to do with the pre-combustion vaporization system. He wanted to know if there is an economic advantage to prevaporizing, perhaps with steam, and atomizing in the combustion chamber. Although I have no direct evidence to substantiate it, I think that it would be advantageous to prevaporize.

Captain Flanagan

I think people have to try these things. Yes, Mr. Matt Winkler.

Mr. Winkler

Two general comments. One relates to a boiler which, I think, is somewhat similar to the one you're discussing. On one of the tests we ran in our government program with steam atomizing nozzles on existing marine boilers, we cut in the emulsion and then proceeded to operate underway, reducing excess air, trimming the boiler, and so on. Due to a problem in the system, the homogenizer and the emulsions had to be cut out momentarily, and, at the levels at which it was operating on steam atomization, the boiler and periscope went black instantly. The only way we could get it back on was to open the registers a very significant amount. So, in answer to your question, it is not a matter of substitution; rather, it is a matter of adding to, and by a very significant amount.

Captain Flanagan

Now Matt, when the emulsor went out, you were pumping, let's say X gallons of emulsion to the burner, some of which was water.

Mr. Winkler

There was a time when we had to break the line.

Captain Flanagan

So when you went to pure fuel....

Mr. Winkler

The boiler was shut off when the unit was shut off.

Captain Flanagan

When you went to pure fuel, you really had more fuel. In other words, if your pump puts out ten gallons of emulsion per hour, and the emulsion cuts out, then you're putting out ten gallons of pure fuel, are you not?

Mr. Winkler

No, because we are bypassing the amount we are not using around the emulsor, i.e., a fixed percentage of the total flow through the unit. The flow to the boiler was actually on less fuel, because we took some water out.

Captain Flanagan

Well, then, that's a pretty valid test if that was really the case.

Mr. Winkler

And that was with existing technology.

Dr. Dryer

They had very similar results in their tests at IFR.

Captain Flanagan

So we had a micro-explosion, and we were getting secondary atomization.

Mr. Winkler

In addition to steam atomization.

Anonymous

Matt, when you said less fuel, didn't you mean less volume? In other words, the water subtracted out more or less fuel.

Mr. Winkler

No, the boiler was set up to operate on a ratio of water plus fuel, and the controller that was holding the flow to the burner,

the automated controller, was set up to hold that ratio against the existing steaming conditions of the boiler. When the unit cut out, and had to be bypassed around it, the flow through the boiler then was controlled on the same ratio, except that there wasn't, you know, water going....

Anonymous

Then, you are talking about the same flow, the same firing rate.

Mr. Winkler

Essentially the same firing rate. The other comment I want to make is that it's impractical to use emulsified fuels on radiant boilers. I've never looked into the situation directly; however, in work with the turbine combustors on residual oil and emulsion we're dealing with a distance that's roughly 18 inches. At 18 inches the residual oil is atomized, vaporized, secondarily atomized, burned, quenched, diluted, and exited into a turbine. Now, distillate is an infinitely easier thing to burn than residual oil with the ends that exist in it. If we can do that in 18 inches, I really find it hard to believe that you couldn't emulsify and burn distillate in the forty or so feet that I heard mentioned.

Dr. Shaler

Well, it's not only the flame length. The long ones are indeed about forty feet.

Dr. Schwartz

Right, It's not only the flame length that's important, but also the radiation characteristic. If you try to heat up a process stream which will come within a very narrow temperature range, then the radiation characteristics of the flame become the most significant parameter in determining the substitutability of fuel.

Anonymous

Whereas, if you've got to completely burn fuel with the rating at the same temperature and the same chemical composition, the

radiation properties will be the same.

Captain Flanagan

Total radiation, but the amount of radiation in the ultra-violet and visible regions can be quite different. I understand that water emulsion can rather significantly change the percentage of energy in these regions, but I don't have any data to prove it.

Dr. Moses

In some of the early work that we did on the combustor, we had a radiation sensor mounted on the primary cell. This was a very wide-angle sapphire window with a solid angle of about 150 degrees. This window did not cut off until somewhere about 5 1/2 microns, so that it got most of the flame radiation below that wavelength. The reductions in flame radiation were about 20 to 25%, with 10% water, and the flame temperature at that water range was down about 10 degrees.

Captain Flanagan

So you have data to indicate that the radiation went down with 10% water.

Dr. Dryer

I feel, from data of different sources, that this reduction in radiation has to do with a reduction in particulate mass and nothing more. There's some work that supports that contention, published in Combustion Science and Technology a couple of years ago by N. M. King, who looked at radiative emissivity of flames which contained additional water vapor. He found no change whatsoever in wavelengths radiated, or in the amount of radiation occurring when they didn't have any particles.

Captain Flanagan

For the layman, it's kind of incandescing particles that are doing us in, and water can reduce those.

Dr. Dryer

The infrared continuum from particles far outweighs any of the

spectral radiation in most of the systems that are really sooty.

Captain Flanagan

So, from a practical standpoint, water can.....

Dr. Dryer

Depending on whether or not there are precursors there.

Captain Flanagan

...Can be of assistance in reducing that radiant heat.

Dr. Shaler

I'd like to add another bit of laboratory evidence, namely that by adding 500 ppm of particle material, this can beat not just coal...I have also added magnesium oxide.

Dr. Dryer

I wish you could convince Professor Essenhigh that it's more particulate than it is the precursor. I fail to see how the spectral radiations from precursors are enhanced by the presence of a water vapor system.

Dr. Shaler

You are, I believe, also confusing two things. This morning, in reply to another question, he made the point that the flame temperature integrated over his furnace is not lowered by the addition of water. This is a direct statement of fact based on the concept of heat balance. The stack temperature is high, and so is the temperature all along the profile.

Dr. Dryer

How does that change the argument you just made?

Dr. Shaler

You're not reducing the radiation, and any buildup of the profile is purely a matter of decrease in particulate.

Dr. Dryer

If I understood him correctly this morning, he mentioned that

most of his change in radiative characteristics of his flame was due to the precursor structure, not the changes in mass of particulates in the flame cell. Is that correct?

Captain Flanagan

I don't think he used the term "precursor."

From the Audience

Yes, he did use the term "precursor." He related the precursor to the smoke, and he may have been referring to the soot which is present in the primary zone as a precursor to the exhaust smoke. That's the way I understood it.

Dr. Dryer

I'm not sure. The word "precursor" has been reserved specifically for the hydrocarbon fragments which precede polymerization and nucleation to solid particles.

Captain Flanagan

Yes, sir.

Mr. Blackburn

I would like to address this to Matt Winkler. In the marine boiler applications, what was the size of the plant, in terms of horsepower, and how much water were you using, translated into tons of water per day or pounds per hour?

Mr. Winkler

On an hourly basis, 8,000 pounds an hour, 5 to 7% water. I don't remember the other one, but I could work it out. It's not very significant because we're using potable water and not evaporator water, and the ship normally carries a more than adequate supply of potable water to take into account that we're talking about. These ships had been considered for higher concentrations of water, but, because of the available evaporative capacity and carrying capacity, the Government elected not to do that.

Captain Flanagan

I believe I questioned where the water came from. I think at least one of the installations is using contaminated drains as your water source.

Mr. Winkler

Yes, we've done both. It really isn't important in the boiler.

Anonymous

Excuse me, water purity is important, though, in the flame in the addition of water to the fuel, as far as the superheating temperature is concerned.

Captain Flanagan

One way to look at it is to take the manufacturer's fuel specifications, such as on metals. He'd have a hard time claiming no warranty if the water in the fuel contaminants plus the water contaminants were still less than his minimums. So far, you've got to have clean water for gas turbines. Small amounts of metal can have quite an effect. Although you're using potable water, East Coast potable water, which is pretty clean, I think you'd have a tough time if you went to Long Beach, where it is terrible. You'd never use Long Beach water.

Anonymous

I have a question of a general nature that I would like to ask. How clean would water injected into gas turbines really have to be?

Captain Flanagan

I believe I can answer that. It depends on the application. The fuel system of a diesel engine and how it operates are uniquely related by operational requirements.

Anonymous

No, gas turbines.

Captain Flanagan

Gas turbines are different. If your're interested in the gas turbine case, then I will defer to Matt Winkler for his comments on the gas turbine case and the cleanliness of water.

Mr. Winkler

Most manufacturers have specifications for water that are extremely strict, to the point where you have to run a great deal of water and require a lot of capital equipment if you're going to do much NO_x reduction with water. That's one of the reasons why we felt this work with emulsions to be significant, because it does cut the water use drastically. We have experience from our gas turbine applications on residual oil using potable water, not distilled or deionized or demineralized, but just shoreside potable water. Granted, it's not Long Beach water, but it is potable, and there's a fair amount of mineral concentration in it. You do not use a lot of water. Even if you wash the turbine occasionally to remove the ash buildup in it, it is not really that great a problem. The manufacturers of gas turbines will disagree strongly, but I'm not a manufacturer of gas turbines, so I can say what I'm saying. If you ask them, they insist on demineralized, deionized, and distilled water, but I have my reservations, as I have noted. I hope my answer is to the point and satisfies you.

Anonymous

How many hours of running are you talking about? I mean running without any problems.

Mr. Winkler

Well, the fleet has an accumulation of a little over 10,000 operating hours.

Anonymous

No, I mean with one engine.

Mr. Winkler

One of the engines has an operating time of over 2,000 hours right now, I believe. The effects of the water are not obvious, primarily because only about 5 percent water is being used.

Anonymous

Do you have any idea what the salt content of your potable water was?

Mr. Winkler

I have it recorded, but I'm afraid I cannot quote it at this moment.

Captain Flanagan

Did you take a sample here in Boston, or New York, or Bayonne, New Jersey?

Mr. Winkler

The sample was from New York.

Captain Flanagan

You could call up the New York municipal water supply agency and they would probably tell you what you're after.

Mr. Winkler

Actually, I have the numbers, but I just don't have them with me, now.

Dr. Dryer

Matt, please answer this question relative to your tests. Do you believe that the amount of mixing distillate and residual that you've got so far is limited by the engine performance characteristics, or is it still limited by the amount of preheat available on the ships? In other words, could you go at a higher mixing rate than you have even now?

Mr. Winkler .

The answer to that is definitely yes. We tripled the vis-

cosity from our initial starting point to 600-second oil, which is about the point where most marine diesels operate on black oil.

The majority of the world's marine diesels operate at 600 or 800 Redwood seconds and below. Most of them do not operate on unlimited bunker for a number of reasons, the primary one being related to exhaust valves. We increased the viscosity from 200 to 600 seconds, and saw almost no change in the operation of the engine, none that we could determine from inspection of the engines, or washing, or watching the performance of the engines through our various monitoring sections. At the present time, our ship tests indicate limitations in the extent to which we can heat the fuel, and also in the amount of heat we can provide at various stages of the system. These limitations will be removed in the future by methods devised to recover waste heat; for the present, however, we must endure these limiting factors.

From the standpoint of the ship's gas turbine, we are extremely limited in the space allotted for combustion systems. We know that pure fuel on the walls of the combustion chamber will affect the walls adversely. Therefore, with the chamber constricted to a space measuring 18 inches in length and width, a number of problems will be simplified if we can come up with a properly proportioned emulsion. For a practical limitation on the turbine engines, we probably would look for between 1000- and 1500-second Redwood oil.

Captain Flanagan

Provided you had unlimited heat.

Mr. Winkler

We will have. Even though we don't now, it's just a matter of time.

Dr. Dryer

You say you might be able to go to something very close to pure residual oil?

Mr. Winkler

Unlimited bunker C in the marine marketplace right now is running 2 1/2% to 3% sulphur and 3500 to 4,000 seconds Redwood. The 1500 bunker has about 10% cutter stock, or distillate cutter stock in it. It's about 90% unlimited bunker. Right now we're running on material that's about 25% cutter stock and 75% unlimited residual. It's pretty heavy stuff, relative to what the gas turbine was designed to run on, but the difference is clearly the emulsion. We've run tests in laboratories using various grades of residual oil in conventional combustion atomization schemes, and the results are very, very short-lived; you get either very heavy fouling rates, or very heavy corrosion rates, or both. Understand that in the present system we're not using air or steam atomizing. We are using conventional mechanical nozzles with the water emulsion as the primary source for providing the necessary fine particles for combustion in a very small confined area.

Captain Flanagan

It's getting late. We still have a lot of comments. Here's a gentlemen who hasn't had a chance to make any.

Mr. Higgins

With regard to a question about water, the Coast Guard put out an addendum in 1967 for auxiliary equipment on shipboard vessels. That addendum says that the Captain, under the jurisdiction of the Coast Guard with a shoreside facility and at the discretion of his Chief Engineer, will accept the water as "drinkable." The water coming on board would be of the type that you could categorize as drinkable if you could use it in the fuel burning application, and vice versa. They won't let anything else on board.

Captain Flanagan

All right. Another question. Yes, sir.

Dr. Tuteja

I want to ask somebody about the purity of water required in

the case of diesels.

Captain Flanagan

Tomorrow we will talk about diesels. I hope there will be some discussion on water quality. The general consensus, according to what I've heard so far, seems to be that the water quality is not a very critical factor.

Mr. Winkler

Tap water is what's been used.

Captain Flanagan

Tap water is what has been used in all of the practical tests that I know of. To my knowledge there has been no indication of problems with it. However, we do not have thousands of hours on a single engine. It may be an old idea, but it hasn't been applied very much yet. Yes, Dr. Dryer?

Dr. Dryer

I'd like to address one other comment that was made about the possibility of secondary atomization with distillate fuels for spray combustion systems. It's something we've looked at, and I am willing to tell you about the data. We haven't published it, because we don't believe that the precision of the results really warrants that at this point. We've done some tests in which we used an air-assisted atomizing approach, as well as a high-pressure atomizing approach, of atomizing distillate materials, No. 2 fuels, home heating oil, into a burner system, a propane air-burner system. That is, we're using the heat of propane-air combustion to support the combustion of the spray. It turns out that the propane air-combustion system is run very air-rich for that reason alone. We have followed the size distribution of the droplets from issuance into the combustion region, through the combustion region, using high-speed flash photomicrography. It's a very difficult experiment, because of the fact that the particles, as they decrease in size, don't follow gas streamlines. Because of that, you tend to look at very small particles; the

large ones just don't follow the gas streamline, and that's where the imprecision in the data comes from. We've been able to see qualitatively from those tests that, indeed, there is a secondary atomization which occurs from comparison of pure fuel atomization and its droplet-size distribution through the flame, with 20% water in emulsion form and its droplet-size distribution through the flame. One finds a very rapid decrease in droplet-size distribution near the flame zone in the case of emulsion. So, there is some evidence, which I again admit, is not conclusive, and this is one of the reasons why we haven't published it. This system that I'm discussing was a one-atmosphere pressure system, based on the boiling point range phenomenon that I discussed earlier.

Dr. Law

But you haven't really taken pictures of microsystems, have you?

Dr. Dryer

Here are pictures.

Dr. Law

These are all really inferences.

Dr. Dryer

These are pictures of droplets and their droplet-size distribution through the flame. We have taken pictures in the case of our suspended droplets, which is more than a presumption - it's a fact - that micro-explosions occur in free droplets of residual oil. There's no doubt about that. In the case of distillates, we are hopefully less than a couple of weeks away from looking at free droplet combustion of distillate emulsions.

Captain Flanagan

In one atmosphere pressure?

Dr. Dryer

In one atmosphere pressure. I'm sorry, not of distillate emulsions, but similar to emulsions based on water and very heavy

alcohols. The reason for this is related to the kind to experimental technique we are using. The very heavy alcohol matches the kind of boiling point that one would find, for example, for hexadecane, in your case.

Anonymous

You are overlooking hydrogen bonding.

Dr. Dryer

Oh, it turns out that those very heavy alcohol molecules are hydrogen bonded.

Captain Flanagan

Gentlemen, it is getting late. If there are no more questions, we'll adjourn until tomorrow, at which time we will continue with papers and discussions on emulsion combustion test results on diesel engines.

(End of Session 3)

SESSION 4

SECTION 1

EMULSION COMBUSTION TEST RESULTS-DIESEL ENGINES

SESSION 4
SECTION 1
EMULSION COMBUSTION TEST RESULTS-DIESEL ENGINES

Captain Flanagan

Welcome to the fourth session of this symposium. We will spend this period examining the timely topic of emulsion combustion test results with respect to diesel engines. Let us begin, then, by listening to the comments of Professor N. A. Henein, of Wayne State University. Professor Henein will base his remarks on his prepared paper entitled "Diesel Injection Systems: Characteristics Which Affect Water-Fuel Emulsion Properties." Professor Henein.

SESSION 4

PAPER 1

DIESEL INJECTION SYSTEMS:
CHARACTERISTICS WHICH AFFECT
WATER-FUEL EMULSION PROPERTIES

N.A. HENEIN

Department of Mechanical
Engineering
Wayne State University
Detroit, MI

DIESEL INJECTION SYSTEMS: CHARACTERISTICS
WHICH AFFECT WATER-FUEL EMULSION PROPERTIES

N.A. HENEIN

ABSTRACT

The severe operating conditions in the diesel injection systems are analyzed, with emphasis on their possible effect on the water-fuel emulsion properties. The characteristics of the following systems are studied: the distributor pump used in the LD465 multi-fuel Army engine, the Unit-Injector used in the 6V-53 Detroit Diesel Allison Division engine, and P-T system used in the NH-250 Cummins engine. The following parameters are studied in each system: fuel recirculation, overflow, cyclic pressure variations, maximum pressure variations, maximum pressures reached, cavitation, and temperatures. The critical areas in the diesel injection systems where the demulsification times might be relatively much shorter than in the continuous injection systems are summarized.

The definitive future studies needed for water-in-fuel emulsion evaluation in diesel injection systems are explained.

(End of Abstract)

Captain Flanagan

Thank you very much, Professor Henein. I have another interesting announcement to make. Late yesterday the Department of Transportation announced the award of a University grant to the University of Michigan. Dr. Fogler, who was one of the presenters yesterday, is the principal investigator. The particular task of this project will involve investigation of the physical properties of fuel-water emulsions. It will be a laboratory effort, and will include consideration of various fuels, water-to-fuel ratios, viscosity, lubricity, corrosiveness, effects on machine parts, and other properties similar to these. I anticipate some interesting results for designers from this effort. I also would like to

mention that the Coast Guard proposed this investigation, and to express my pleasure that DOT has agreed to fund it.

The second paper this morning is on engine performance and fire safety characteristics of water-containing diesel fuel. There are going to be two presenters, Mr. E. C. Owens and Mr. B. R. Wright, both from the U.S. Army Fuels and Lubricants Research Laboratory. Mr. Owens will lead off, and will then introduce Mr. Wright for his supplementary remarks. Mr. Owens.

SESSION 4

PAPER 2

ENGINE PERFORMANCE AND FIRE
SAFETY CHARACTERISTICS OF
WATER-CONTAINING DIESEL FUEL

E. C. OWENS AND B. R. WRIGHT

U.S. Army Fuels and Lubricants
Research Laboratory
San Antonio, TX

ENGINE PERFORMANCE AND FIRE SAFETY CHARACTERISTICS
OF WATER-CONTAINING DIESEL FUEL

E. C. OWENS AND B. R. WRIGHT

ABSTRACT

Recent flammability evaluations conducted at U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) have shown that water-containing diesel fuels are more fire resistant (even at temperatures above the flash point) than the same fuel without the water added. These findings led to this project to evaluate the compatibility of such fuels with a full-scale diesel engine and to further assess the fire vulnerability reduction imparted by the water.

Blends of base diesel fuel plus 2-percent surfactant plus as much as 10-percent water were evaluated in an unmodified LDT-465-1C engine, a multi-fuel diesel engine with wide field use by the U.S. Army. No significant changes were observed in power output when operating the engine at equal base fuel flow rates. The smoke reduction effects were inconclusive, but the nonvisible emissions were substantially altered. Oxides of nitrogen emissions were decreased as much as 30 percent, but were accompanied by a 250-percent increase in unburned hydrocarbons. Ballistic tests conducted with 20mm high-explosive incendiary tracer rounds demonstrated diminished fireballs and self-extinguishing ground fires at temperatures 14 degrees C (25 degrees F) above the base fuel flash point. Tests with the base fuel alone resulted in catastrophic fireballs and ground fires under such conditions. When 0.1 percent of a polymeric hydrocarbon antimist agent was added to the 10-percent (or 5-percent) water multiphase fuel, fire effects were almost totally eliminated.

The potential fire-safety benefits and lack of major detrimental engine effects make these water/fuel blends attractive candidates for fire-resistant fuels.

(End of Abstract)

Captain Flanagan

Thank you very much, gentlemen. We will continue with our next speaker, now, and save our questions for the discussion period, which will occur immediately after the coffee break. I now introduce the next speaker, Mr. W. F. Marshall, of Bartlesville Energy Research and Development Administration (ERDA). His paper is entitled "Use of Water-Fuel Emulsion in a Diesel Engine: Test Results," Mr. Marshall.

SESSION 4

PAPER 3

USE OF A WATER-FUEL EMULSION
IN A DIESEL ENGINE: TEST RESULTS

W. F. MARSHALL

Department of Energy
Bartlesville Energy Research
Center
Bartlesville, OK

USE OF A WATER-FUEL EMULSION IN A DIESEL
ENGINE: TEST RESULTS

W. F. MARSHALL

ABSTRACT

The Bartlesville Energy Research Center is conducting an on-going research project involving control of emissions from engines operated in underground mines. The use of water-fuel emulsions has been suggested as a means of reducing emission levels while maintaining, or improving, fuel economy. In order to allow assessment of the potential benefits of water-fuel emulsions, tests were conducted in which a heavy-duty diesel engine was operated on diesel fuel and an emulsified mixture containing 20 percent water-80 percent diesel fuel.

Results of these tests indicate that the use of the emulsified fuel did not yield any benefits with respect to emissions or fuel economy.

(End of Abstract)

Captain Flanagan

Thank you very much, Mr. Marshall. I hope all of our audience will stay on for the remaining presentations, because, interestingly enough, we are going to hear of test results which provide data just the reverse of most of the data given us until now. This is indeed a strange situation, one which leads the Coast Guard to conjecture as to why valid and accepted test procedures by respected researchers should produce such conflicting data. There must be **some reasons** for these valid research data being so different. I don't know for sure what they are. The work that's been reported so far this morning does, in fact, always include a chemical surfactant. That may be a key. There may also be some droplet-distribution size effect, and perhaps other effects that we haven't even gotten close to yet.

Now we will go the next paper presentation, to be given by Bob Walter, of the Transportation Systems Center, who has contrib-

uted so much to setting up this conference. Bob's paper relates to work being done here at the Transportation Systems Center, and is titled "Use of a Stabilized Ten-Percent Water-in-Diesel Fuel with a Detroit Diesel 6-71 Engine." Bob.

SESSION 4

PAPER 4

USE OF A STABILIZED TEN-PERCENT
WATER-IN-DIESEL FUEL WITH A
DETROIT DIESEL 6-71 ENGINE

R. WALTER

U.S. Department of Transportation
Research and Special Programs
Administration
Transportation Systems Center
Cambridge, MA

USE OF A STABILIZED TEN-PERCENT WATER-IN-DIESEL
FUEL WITH A DETROIT DIESEL 6-71 ENGINE

R. WALTER

ABSTRACT

Stabilized water-in-fuel emulsions were run in a marine-configured Detroit Diesel 6-71 engine on a dynamometer test stand. Measurements were made of engine performance, fuel consumption, and emissions. The engine was operated at variable speed and variable load conditions to simulate propeller loading, and at constant speed and variable load conditions to simulate generator loading. In addition, the injection timing was varied from normal to 7.2° of retard and 7.2° of advance in 3.6° intervals. At all test points the engine was run with both normal fuel and emulsion. The emulsion used was 10% water in fuel with 2.5% stabilizer which produced an average droplet size of approximately $1\mu\text{m}$. The engine performed well with emulsion with a slight degradation in fuel economy at normal and advanced injection timing and no change at 7.2° or retarded injection timing. In general, with emulsions, NO_x and smoke decreased slightly, UBHC increased significantly, and CO either increased or decreased, depending on engine speed and load.

(End of Abstract)

Captain Flanagan

Thank you very much, Bob. I think it would be wise now to move on to the next two papers, which take the approach of no chemical surfactant running in diesels. This appears to be quite a difference from the previous approach. After the paper presentations we will have a little time for discussion. A number of our group wish to be heard relative to the material we're discussing today. What we'll do is to permit them to present their comments, after which we will allow questions from the floor. We'll hear from as many requestors as our time schedule will permit, and in this way, perhaps, we will come closer to the true

situation.

The next paper, to be delivered by our United Kingdom friends, is going to be dually presented, with Dr. R. V. Thompson leading off, and Mr. A. B. Constantine following. First, Dr. Thompson.

SESSION 4

PAPER 5

THE APPLICATION OF EMULSIFIED
FUELS TO DIESEL ENGINE
PERFORMANCE

R. V. THOMPSON AND
A. B. CONSTANTINE

University of Newcastle-upon-
Tyne
Newcastle-upon-Tyne, England

THE APPLICATION OF EMULSIFIED FUELS
TO DIESEL ENGINE PERFORMANCE
R. V. THOMPSON AND A. B. CONSTANTINE

ABSTRACT

Detailed are the results of tests applied to a series of diesel engines. The results obtained involve a range of fuel oils and, in all cases, the use of ordinary tap water dispersed as a water-in-oil emulsion applied to the main supply pump.

The latest results apply to high-speed diesel engines capable of producing approximately 170 BHP at 2000 RPM. The results of both the laboratory tests and road trials indicate average fuel savings in excess of 5%, together with a reduction of oxides of nitrogen averaging 50%. In all cases, a proprietary emulsor has been used to produce the required emulsion.

Illustrations are provided of the test results and various components of a stripped-down high-speed diesel engine which has completed approximately 12 months of experimental abuse.

(End of Abstract)

Captain Flanagan

Thank you very much, gentlemen. We are engaged in a single-cylinder diesel test program, one that's going to be talked about in the next paper. In connection with our fuel emulsion work in the Coast Guard, we learned, through an American manufacturer, of Dr. Thompson's work in Great Britain, and of his application of a particular emulsor, and of the availability of some data on diesels. We were provided these data, and on reviewing them, we found them quite promising. At the time, there was some question as to whether we should incrementally increase our funding for work by Southwest Research Institute, through the Transportation Systems Center, relative to a different emulsor operating in a different way. Before deciding to spend that money, I went over to Great Britain to see if the data were real, and to get some more information on the truck engine and the six-cylinder diesel engine

mentioned by these gentlemen. They started the engine, and showed me where the controls were. I tested the water. It didn't have ether or any other chemical in it. In fact, it was just plain tap water. I asked them to set up some more instrumentation for the engine under test, because I wanted to know a little bit more about how much power the emulsor was absorbing. In terms of horsepower, their data indicated one-tenth horsepower. When they left the area, I took some data myself, and my data points fell statistically within theirs, so I believe the graphs they showed me. With engine operation at near top speed, medium speed, and low speed, I have obtained the same data on the same engine. We are definitely interested in those emulsions.

Now we will hear from Mr. John Storment of Southwest Research Institute. He will discuss emulsified fuels in single-cylinder diesel engines. The paper on which his comments are based is titled "Ongoing Tests with Emulsified Fuels in a Single-Cylinder Diesel Engine." Mr. Storment.

SESSION 4

PAPER 6

ONGOING TESTS WITH EMULSIFIED
FUELS IN A SINGLE-CYLINDER
DIESEL ENGINE

J. STORMENT

Southwest Research Institute
San Antonio, TX

ONGOING TESTS WITH EMULSIFIED FUELS IN
A SINGLE-CYLINDER DIESEL ENGINE
J. STORMENT

ABSTRACT

A single-cylinder, four-stroke cycle diesel engine was operated on unstabilized water-in-fuel emulsions. Two prototype devices were used to produce the emulsions on-line with the engine. More than 350 test points were run with the baseline diesel fuel and emulsified water-in-fuel. The water content of the emulsified fuel varied from about 2 percent to more than 23 percent by volume. Statistically significant decreases in fuel consumption, ranging from 1.5 percent to 5 percent were obtained with emulsions in 20 out of 36 speed/load conditions at which the engine was operated. An increase of 2.5 percent was measured at one condition only. Use of the emulsified fuels decreased oxides of nitrogen by up to 60 percent and Bosch Smoke Numbers by up to 70 percent, whereas unburned hydrocarbons increased up to 130 percent. Carbon monoxide changes with emulsified fuel varied from a decrease of 50 percent to an increase of 170 percent, depending on speed, load, and water content of the fuel. No problems were encountered in engine operation at any test point with the water-in-fuel emulsions used.

(End of Abstract)

Captain Flanagan*

We have a whole series of requests to make comments relative to the material that has been presented today. I'm going to try to get through them, and then open the floor for questions or comments. Dr. Dryer feels that he has some valid material, soon to be published, which is directly related to the apparent anomalies that we are seeing in reported data on diesel fuel consumption with and without surfactants. He will be followed by Mr.

* Captain Flanagan's statement reopens Session 4, which was recessed at the end of a discussion period on Mr. Storment's presentation.

Jim White, who will briefly explain the difficulties in characterizing the emulsion on the work that has been reported by Southwest Research. Then Professor Henein will describe his feelings on the use of emulsions in diesel systems, using blackboard demonstrations. Dr. Murayama, of the University of Hokkaido, Japan, would like to tell us about work going on in Japan relative to small emulsors. So, let us lead off with Dr. Dryer.

SUMMARY OF REMARKS ON
CAV LTD EMULSION TESTS

F. L. DRYER

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SUMMARY OF REMARKS ON CAV LTD EMULSION TESTS

F. L. DRYER

Dr. Dryer summarized the results of a study by CAV Ltd., of Great Britain, on water addition to diesel combustion. Using a four-cylinder research engine with one cylinder modified for special water addition, CAV studied the effects of this addition through the following methods:

- o Aspiration through the air intake
- o Direct injection into the combustion chamber with a second injector
- o Coinjection, with fuel mixed in the injector
- o Coinjection, with fuel mixed before the injector.

The results of these tests indicated that:

1. Injection delay time increased with increasing water content.
2. UBHC emission increases were small until misfires became a problem.
3. CO emissions were significantly different when the water was aspirated or directly injected.
4. NO_x emissions were reduced up to 80% with 30% water directly injected.
5. Soot (smoke) emissions were reduced more than 80% with 30% water directly injected.
6. Fuel economy was basically unchanged.

CAV concluded that secondary atomization played no role in the results, because the water and fuel droplets were separate. However, based on the observed soot reduction and "spike" in the combustion pressure, Dr. Dryer disagreed with this conclusion.

(End of Summary)

Captain Flanagan

Jim White would like to comment on the difficulty in characterizing the emulsions that are being used on the single-cylinder test by Southwest Research.

SUMMARY OF REMARKS ON
EMULSION CHARACTERIZATION

J. WHITE

U.S. Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, DC

SUMMARY OF REMARKS ON EMULSION CHARACTERIZATION

J. WHITE

Mr. White (USCG, R&D) presented the results of characterization tests of the water-in-diesel fuel emulsion produced by the Daedalean Associates, Inc. (DAI) cavitating emulsor. These tests were performed at DAI's facilities and at Southwest Research Institute (SWRI) during the single cylinder engine tests (see abstract of Paper 6, Session 4, by J. Storment). These characterizations were by measurements of demulsification times, photomicroscopy, and visual observations. The results obtained are listed below:

1. Contrary to previously reported results, the DAI emulsor did not produce emulsions that were stable for two to three weeks. The period of stability was only a matter minutes.
2. With a relatively cool emulsion ($<75^{\circ}\text{F}$), separation of water and fuel was complete in approximately ten minutes.
3. With a warmer emulsion ($75^{\circ}\text{-}80^{\circ}\text{F}$), separation is complete in approximately five minutes.
4. Based on sedimentation theory, the emulsion droplet diameters are $100\text{ }\mu\text{m}$ to $300\text{ }\mu\text{m}$.
5. The single-cylinder-diesel-engine (SCDE) transfer pump slightly degraded emulsion stability.
6. The SCDE fuel injection pump slightly enhanced emulsion stability.
7. The SCDE injector output was an emulsion.
8. Photomicroscopy was of limited value in characterizing emulsions because of the rapid creaming rates in conjunction with the time involved in getting the sample to the microscope.

9. A device that can size and count emulsion droplets on-line is needed, but is not available.
10. An emulsion in excess of 20% water was too unstable to be run with the SCDE.

(End of Summary)

Captain Flanagan

Now Professor Henein would like to convey some thoughts relative to diesel systems and the manner in which emulsors and emulsions might be affected by the diesel fuel system itself.

SUMMARY OF REMARKS ON EMULSIONS
AND THE DIESEL FUEL SYSTEM

N. A. HENEIN

Department of Mechanical
Engineering
Wayne State University
Detroit, MI

SUMMARY OF REMARKS ON EMULSIONS AND THE DIESEL FUEL SYSTEM

N. A. HENEIN

Professor Henein explained the differences in fuel injection systems among diesels, and between diesels and the spark ignition engine. He discussed the physical characteristics of the direct injected and prechambered diesel engine, and the relationship of these characteristics to diesel combustion, fuel consumption, and emission formation. In the course of his talk he presented a number of observations, of which the following are representative of the overall approach to his presentation:

1. Slow-speed engines have shaped injector spray patterns and low combustion chamber swirl characteristics.
2. High-speed engines have simple injector spray patterns and high induced swirl characteristics.
3. Depending on engine speed, type, and operating condition, from 10% to 70% of the fuel droplets hit the cylinder walls. Some of these droplets may rebound from the walls, whereas others may stick.
4. The fuel on the cylinder walls is heated up by conduction from the wall, and ignited later in the combustion process.
5. It is not known whether, in the burning of an emulsion, the fuel on the walls would micro-explode.
6. The ignition delay period is the most important single combustion criterion in the diesel engine. It determines the ratio of premixed to diffusion types of combustion.
7. Emission production is directly related to the fuel consumption and the ratio of premixed to diffusion combustion.

(End of Summary)

DISCUSSION PERIOD

Anonymous

Did you say that at high loads more fuel would be on the walls? That seems to contradict your previous indication that there was more fuel in the spray.

Professor Henein

Yes, it should be on the wall.

Anonymous

Typically, what fraction of fuel would be burning off the wall?

Professor Henein

If you're talking about light loads, you could expect about 10 percent of the total to hit the wall. In cases of high loads, figure about 70 to 75 percent.

Anonymous

Seventy percent on the wall?

Professor Henein

Oh, yes.

Captain Flanagan

For long periods of ignition.

Professor Henein

Yes. At full load the fuel hits the wall and stays there.

Captain Flanagan

But you must admit this is very much a function of the engine design.

Professor Henein

Of course. I'm talking about high-speed engines. With slow-speed engines, you'll find that this might be five or ten percent, but with high-speed engines a good portion of the fuel hits the wall.

Dr. Wilson

Is it your understanding that this fog of fuel droplets in air that's coming out of the injector hole collapses into a liquid film at the wall, or does it bounce off and make another jet, a wall jet?

Professor Henein

Well, part of it would be reflected, but the majority would stay on the wall. The liquid, as you know, does not bounce like a tennis ball. Once it hits the wall it forms a film. Part of it will be reflected due to the initial energy, but most of it will remain on the wall.

Dr. Wilson

In the current models of this wall jet phenomenon, e.g., the CAV model, it forms a spray on the wall.

Professor Henein

As you probably know, most of these models fail to simulate the combustion diesel engine. In fact, people are working on models even now, and as yet are not considered as representing what happens in the engine. The CAV model is just one of the models being used, but is not the model representing combustion in diesel engines. I know about six people who are right now working on developing a model for combustion in open chamber diesel engines.

Anonymous

Was there direct evidence that 70 percent of the fuel is in a liquid film on the wall?

Professor Henein

That's about right. If it's lower, we haven't measured it, but my guess is that 70 percent is about right.

Dr. Dryer

Spray penetration is a direct function of the droplet size.

If secondary atomization is important, the penetration must have changed.

Professor Henein

I doubt that secondary injection would take place before the fuel hits the wall.

Captain Flanagan

Gentlemen, I think the discussion is quite useful. On the other hand, we've got a lot of ground to cover, and I think we're getting into areas where very little data are available. I think it's quite useful to realize that this may or may not be a problem. I would like to move on, and if you could wrap up, I'd appreciate it.

Professor Henein

Let me mention another system design, the "M" system referred to this morning. In this system, injection of the fuel toward the wall provides for control of evaporation and temperature of the film. The original design of the engine in this system requires that there be no separation between the vapor and the wall, and that a certain optimum surface temperature should exist at which the system is to operate. According to the theory of this system operation, the vapor diffuses away from the liquid and forms a mixture. About 5 to 10 percent of the fuel is then injected into the engine in the form of droplets before ignition. Thus, the fuel is believed to contain a premix charge of fuel with air.

Now, what can we say about the performance of the emulsion in this film? I don't yet know, nor do I know, as of now, where microexplosions will take place. We need to find an answer to this. The answer to this question may also explain why some of the results shown on the LD-465 engine differ from those on the Detroit diesel engine, or from those conveyed to us by our colleagues from the United Kingdom.

Another engine that commands our attention is the swirl engine. Our involvement with the various types of engines shows the need

for understanding the combustion process in diesel engines before we can understand their effects on emulsion. We should be able to provide a graph relating water-in-fuel emulsion, ignition delay, and cetane count number. In fact, the designer, by looking at the cetane number, could come up with the ignition delay, and trace the possible source of engine noise, which could then also be verified by a cycle analysis. One of the problems we must contend with concerns the relative values of the cetane number and the compression ratio at which the engine test is made. If we have a cetane number less than 15, we will have to deal with very high compression ratios whereby to rate the fuel. If we use emulsions in fuels for which the cetane number is low, we get into an area where the tests for cetane number become unreliable. For this reason, we have come up with a new scheme which enables us to obtain the zero cetane number. This new procedure would be very suitable for rating diesel fuels.

Captain Flanagan

Thank you, Professor Henein. There are two more people who would like to speak to us relative to small emulsors. Also, I would like an answer to this question before we move away from consideration of diesels, and diesels burning fuels with surfactants and water, and diesels burning nonsurfactants emulsions. Does anyone have any results, or theories that are close enough to test results, that might shed light on why the surfactanted fuel does not give the results, in many cases, that the non-surfactanted emulsion does? Yes, sir.

Dr. Tuteja

My comment is not strictly related to whether or not surfactants have any effect. I do wish to point out, however, a difference between those engines which have shown reductions in NO_x and others which have not. Today you have heard Dr. Dryer refer to test results which indicated NO_x emission reduction in the CAV engine. I, for my part, refer you to test results on NO_x reduction published by Cummins five or six years ago. The distinguishing feature which I stress is that both Cummins and

Detroit Diesel injection systems are very-high-pressure injection systems, whereas all the injection systems used in the other engines are Bosch-type injection systems having lower peak injection pressure. I would like to hear some additional opinions on this.

Dr. Dryer

I would like to make sure that the results represented here as well as the Cummins work represent all the work that has been done in the field with diesel and diesel emulsion. There has been work extending back to 1953 by Cornet and Nero at the University of California at Berkeley. They published two papers in Industrial Engineering Chemistry. There have been more recent papers published by Vichnievsky et al. at the CIMAC conference in Barcelona, Spain, in April of 1975. The paper is probably available from the University of Paris in French. We have translated the paper at the Guggenheim Laboratories. It's a very rough translation, but it would at least allow one to see what it's about. The interesting thing about the CIMAC paper is that they actually did what Professor Henein suggested that somebody should do. Essentially, four different engines were involved, and I can tell you what they were: models MONO 520NS, Riccardo E6/T, Poyard 6L85, and Agrom 472. These models cover the range of combustion chambers from open to Comet V, to toroidal, to open; some types of injection systems from direct to swirl; and a number of different compression ratios and a number of different injector sizes. They have made some general conclusions as to the results. The general conclusions read something like the following: "The injection in a compression ignition engine of an emulsion of oil and water presents a certain interest concerning reductions of emissions in oxides of nitrogen at the exhausts. This reaction can attain very large proportions, as high as 70 percent in comparison with engines fed with pure fuel oil. It is the same for the emission of soot which permits the increase in power of certain engines by 20 percent, keeping the same smoke limits, corresponding to operations, with pure fuel. The efficiency can be slightly increased or

decreased, depending upon engine design and operating configuration. The emission of carbon monoxide is diminished from 30 to 50 percent from direct injection engines and increased for swirl injection engines, remaining, however, within acceptable limits. Good operation of the engines imposes a limit of 20 percent of water in fuel emulsion structure. Above this value, starting is difficult; at low speeds the ignition occurs badly, and unstable operation may result. Another limit of the utilization of emulsions may be the mechanical integrity of the motor due to the high pressure spike which occurs upon ignition. The emulsions increase, often considerably, up to 200 percent, pressure gradient beginning with the ignition." That paper is relatively comprehensive on this kind of study. I should say that all that work done by Vichnievsky was done with stabilized emulsions, and not with dispersion systems. There have been a number of other unreported studies and unpublished studies which again have corroborated, as I have said before, the resids (residual fuel oils). I believe that, in general, the last three papers are comparable in the end results.

Captain Flanagan

Well, how do you explain the results of the work in the Bureau of Mines, and of the Navy's work with surfactanted fuel where there was no apparent improvement in efficiency, and really not much improvement in emissions?

Dr. Dryer

There is a problem with surfactant stablized emulsions in many systems, including such systems as the Bosch or high-pressure injection pump systems. We have performed experiments on high-pressure homogenization of surfactant stabilized diesel emulsions, and have found that above some pressure between 3,000 and 5,000 psi the surfactant is essentially destroyed.

Captain Flanagan

What did you get?

Dr. Dryer

Good question. It's literally destroyed in a high-pressure process. No chemical analysis has been performed, but I can guarantee you that the surfactant is destroyed, because the emulsion is destroyed. Its stability is destroyed.

Anonymous

Is that true for the Gaulin system?

Dr. Dryer

That's exactly the system on which the experiments were performed. For pressures above 5,000 psi, one gets into trouble.

Anonymous

Are you saying that you get so much energy that you can break down many of the polymer type emulsifiers?

Dr. Dryer

I think that is part of the problem. I would have to admit that, as I see it, a goodly share of the quality of the dispersion has nothing to do with what we do anywhere in the feeding system except in the injector. If we can get a good uniform dispersion, regardless of the size of the injector, then, depending on the design of the ejector, we will obtain a certain performance characteristic.

Dr. Moses

I'd like to point out one other major difference between the diesel work and the boiler and turbine work that may play a role in this, namely, the typical dropsize of the spray. In the pressure atomizers that we find in turbine engines such as I used, the SMD of the spray is typically on the order of 75 microns, significantly larger than dispersion sizes that we have been talking about (e.g., in the range of 1 to 3 microns). In diesel engines the spray size is generally lower than 10 microns, and may actually be down in the range of below 5 microns. Now we're down very close to the dispersion size that we're talking about.

Captain Flanagan

Not only that, but we just had to go through a little poppet valve, which is itself a homogenizer.

Mr. Kinney

Going to Jim White's comments on trying to look at stability or to evaluate the emulsion quality to determine whether you have emulsions, we have had similar problems making determinations microscopically on light fuels. It's impractical. First you get a clustering of water droplets, and then a coalescing effect. We tried to run experiments similar to your procedure of using a settling technique and watching for creaming. When you get to the point of creaming, the emulsion is broken much earlier than that point.

Mr. White

I agree.

Mr. Kinney

You have, first of all, a clustering effect, then a coalescing effect, and then a Stoke's Law effect. By the time you see the creaming, the emulsion will already have been long ineffective. What we have seen on light fuels not stabilized is that they will break instantaneously - in a matter of two or three seconds. Suppose, for example, that you have an emulsion with 15 percent water. In our opinion, at least half, or more, of that water immediately becomes ineffective in that it is either clustered or coalesced to five, or ten, or much larger water droplet sizes. This accounts in part for the fact that when you think you have 15 percent, you have only two or three percent, or two or three micron size, that is effective relative to the primary droplet size. This is one of the major questions concerning the required water droplet sizes; it is definitely related to the primary atomization droplet size.

Captain Flanagan

From these results you could categorize the emulsion as going

downhill at the low-pressure pump, and uphill as it goes through the high-pressure system, and as for what we get out of the ejector, there is uncertainty involved.

Dr. Tuteja

I wish to comment on Dr. Moses' statement on droplet size. We have calculated the Sautier Mean Droplet size, according to the established correlations, to be between 20 and 30 microns rather than between five and ten microns.

Captain Flanagan

Are you referring to the Cummins engine?

Dr. Tuteja

No, Detroit Diesels.

Captain Flanagan

Detroit Diesels are on the order of 20 to 30 microns?

Dr. Tuteja

Twenty to thirty microns. It all depends on such factors as what injector you are using, the size of wall, and so on.

Dr. Law

I have a partial hypothesis on the effect of the emulsifier on the droplet combustion process. If I may, I can briefly outline it. I think it will really change the vaporization process. Yesterday I discussed how the droplet would vaporize. If you have a parent droplet and a water micro-droplet, but no emulsifying agent, then it is possible that the water micro-droplet and the fuel are both accessible to the hostile environment, and they can both vaporize. However, if you put in an emulsifying agent, the surface tension will probably prevent the micro-droplets from getting into the gas phase, so that it may not be possible to vaporize them all. As a droplet vaporizes, there will be more than a micro-droplet to keep on pushing inside. Then what you're really vaporizing initially is probably just the fuel. If this were influenced by how much fuel and water you can deliver outside

the combustion chamber and by the droplet temperature and the micro-explosion, then you could determine how easily you can get the water droplets outside and cause them to vaporize.

Captain Flanagan

That's a very interesting hypothesis.

Dr. Dryer

Mr. Wright reported some results this morning that don't seem to corroborate that at all. He showed results on flash temperature of the material was suppressed by water-and-fuel surfactant-stabilized emulsions, and the only way you can suppress flash temperature is to suppress the vaporization rate of the fuel.

Anonymous

I also would like to comment on Dr. Law's hypothesis. In all the ignition systems that we're familiar with and which have published results available, there is a delay in the ignition. The law of ignition delay would seem to indicate that there is a loss of evaporation. This is based on the fact that local evaporation of the water would reduce the local temperatures, and this temperature reduction would increase the delay. These data do not corroborate the hypothesis suggested by Dr. Law.

Captain Flanagan

Maybe the hypothesis ought to be given a little further consideration.

Dr. Moses

I'd like to recommend an experiment for use here similar to one that is already being performed at SWRI. In that experiment a single-cylinder picture-window type of engine is used to permit taking of high-speed motion pictures of initial stages of the combustion process, injection, and flame speed. This work has made possible observation of differences between premixed areas, and the diffusion flames and the burning fuel spray.

Captain Flanagan

That sounds very interesting. At the same time, taking motion pictures of diesel combustion chambers while the engine is running is not a trivial matter. We would like to do a lot of things, but they involve more money than we have available.

Dr. Dryer

We have done testing on the relative decay rates and the maximum particle size and internal phase size, produced during decay versus time in very dilute water-fuel emulsion structures, unstable and with no surfactant. In these tests we performed a dynamic photographic process, in which we made a crude premix of the water and fuel, using a Waring blender and a magnetically coupled gear pump operating at a very high speed - nearly 10,000 rpm. We were using that approach because we were certain that we were not contaminating the system in terms of any source of natural surfactants. The test runs used combinations of n-dodecane and water - 97 percent pure n-dodecane, and water. The reason for the very small percentage of water was the opacity of the material. Our interest centered essentially on the downstream of the high-speed pump. We installed a commercially available, high-intensity ultrasonic emulsifier, which is currently being marketed in the United States. On the downstream of the emulsifier, we split off part of the flow, roughly 18 gallons per hour and between 10 and 40 psi, and passed it through a very narrow optical, transparent section. We then backlighted that section with a high-speed, high-intensity strobe and photographed the internal phase droplet size, using about 20-power magnification and a 35-mm lens at 1,000th of a second. We found that the decay time for an emulsion structure that is unstabilized and has no availability of natural surfactants is much faster than the two or three seconds suggested by Mr. Kinney. We believe it's less than tenths of seconds to decay to particle sizes of 70 microns or more. And I must again emphasize that these 70-micron particles were obtained with only one percent of water added to the system. As we went to higher percentages of water addition to the system, we could see an

increase in the number of small particles that were still available in the system, but the number of large particles also increased. Again, I emphasize that one 70-micron particle is worth a lot of one-micron particles. We also found some interesting things with regard to this commercially available ultrasonic emulsifier. The emulsifier system alone cost well over two thousand dollars. We ran it forwards, backwards, and with several different pressures and spacings between the anvil and the transducer. There was no discernible difference between the respective detected outputs from the high-speed gear pump and ultrasonic emulsifier.

Professor Thompson

I would like to refer to a certain peculiarity which limits the widespread applications of the ultrasonic devices. Specifically, the pressure within the cavitation area, i.e., between the anvil and the hammer, must be maintained at between 15 and 24 psi.

Dr. Dryer

That's right. The pressure range you mentioned falls within the region I just defined, and is well within the range recommended by both commercial and manufacturing sources.

Professor Thompson

Well, this means, of course, that you can operate at only one flow ratio. So, if you want to go to a fully modulated system, you'll find it difficult to achieve through the medium of ultrasonics. There is another very interesting point that has been brought out this morning. With respect to high distillates, as we have indicated from our own tests, you cannot maintain a significant emulsion for a very long time. We're talking in terms of twenty or thirty seconds, or thereabouts. If, on the other hand, you're talking about the heavier fuel oil, then, of course, you can maintain the emulsion for an indefinite period.

If we divert slightly from the immediate topic of the conference and take a look at the world-wide supply of fuel, we will be reminded that there is only one main source of high distillate,

namely, the North Sea. Even that supply will run out by about 1990. Consequently, people are going to be concerned with the use of heavy crude oil, residual oil, and so on. It seems to me that we have emphasized high distillates at the present time, when we ought really to be talking in terms of the residual oils and muck that will be thrown into the exhaust system.

We must also recognize the fact that fuel is going to become so much a liquid fuel commodity that it's going to be very difficult for an automobile user to have access to liquid fuels. Consequently, we may have to move away from that area. It seems also that as far as the diesel engine is concerned, the diesel engine manufacturers should start thinking about alternative fuels. In the 1930s, for example, we were running diesel engines on coal. Maybe we will have to do it that way again.

The main point, as I see it, is that we are at the moment stressing high distillates as a short-term solution to the energy crisis, and that with reasonable application of emulsified fuels we can realize results that appear possible to attain and which will also provide us with a tolerable interim period. Within the next five or ten years we'll have to deal with heavy, mucky type of fuel. When that type of fuel comes to be used, then application of water to the fuel will provide the kind of environmental control that will be definitely needed. These are some of the problems that we'll have to confront in an overall approach.

Captain Flanagan

Unfortunately, Dr. Thompson was not present at yesterday's conference, and hence is unaware that these points were brought out for gas turbines and boilers, and to some extent for low-speed diesels. There's no question about the fact that we're going to have to learn how to burn inferior fuel. We can expect to use some really bad stuff in the long-term - actually in the not too distant future. We're existing now on a sort of short-term respite by concentrating on existing diesel engines and the like.

I want to talk a bit about the discussions to be held after lunch. The discussions are going to concentrate on two areas. They will provide you with the opportunity of investigating the direction which this country should take in developing systems directly related to the energy crisis.

First, please try as quickly as possible to establish some minimum data reporting guidelines from research in this area. If you cannot come this afternoon, please fill out the discussion card and give it to me so that I can take advantage of your feelings on how we should report data in this area. We'll go through them as rapidly as we can, and attempt to obtain a consensus. If we cannot obtain a consensus on that particular type of data reporting, we will indicate it in the report as having obtained no consensus, and leave it open for a percentage vote. Please do that quickly.

Secondly, I would like to initiate discussion on where we go from here. We will want to get answers for questions such as:

1. How should the Federal Government and industry use the information provided here and the data being made available?
2. Where should we look next?
3. What is needed most?
4. What will provide the maximum beneficial returns?

We here are a technical group which can furnish technical guidance to politicians, bureaucrats, and industries. I feel that many of you have strong sentiments about what should be done next. Should we ask the instrument manufacturers to proceed with development of a system that allows us to measure particle size distribution in the free stream, or is it more important to concentrate on residual fuels than on distillates, and where in particular? Should we point out to people that emulsion burning must be tailored to application, not only in gas turbines and boilers, but also in diesels? It's that kind of input that I'll need from you to wrap up a good final report that will carry some weight, and to

help me to get some things done. There are people present at this conference, and others on the outside willing to listen to us, who are in a position to make a real difference.

We have two more presenters who would like to summarize the results of work that has been done and has not been reported on today. I would like to call on Dr. Murayama of the University of Hokkaido, Japan, who will speak to us about emulsors being developed in Japan. Dr. Murayama.

SUMMARY OF REMARKS ON THE
USE OF EMULSIONS IN FURNACES
AND DIESEL ENGINES

T. MURAYAMA

Department of Mechanical
Engineering
University of Wisconsin
Madison, WI

SUMMARY OF REMARKS ON THE USE OF EMULSIONS IN
FURNACES AND DIESEL ENGINES

T. MURAYAMA

Prof. Murayama has used oil-in-water emulsions to incinerate liquid organic wastes in a furnace, and water-in-oil emulsions to power a single cylinder, fishing boat, diesel engine. He concentrated his remarks on the method used to produce water-in-oil emulsions. The emulsions were produced in static mixers which were developed in association with Toray Engineering Co. LTD, Japan. Two sizes are available. One is 6 cm long, 10mm in diameter, and has three mixing cells; the other is 8 cm long, 10 mm in diameter, and has five mixing cells.

A non-ionic surfacant made from cow-bones was used in order to avoid secondary pollution from metallic ions. Emulsions containing up to as much as 80% by volume of water to diesel oil were made, and burned in the engine. The surfactant concentration was held to between 1.0 and 1.5%. The emulsion produced in five passes through the static mixer has a water droplet diameter of approximately 3 microns. The emulsions produced are relatively stable. It takes 40 days for a 20% separation of the emulsion to occur. The separation occurs in the form of oil on the upper surface of the emulsion. Prof. Murayama feels that this indicates that the water remains emulsified, thus eliminating possible corrosion problems.

(End of Summary)

Captain Flanagan

What kind of oil did you use?

Dr. Murayama

Diesel oil.

Captain Flanagan

Standard marine diesel oil?

Dr. Murayama

Yes. I don't know the rated number.

Captain Flanagan

All right. And you say 80 percent water?

Dr. Murayama

Yes, added to oil.

Captain Flanagan

To oil, but you still claim to have a water-in-oil emulsion?

Dr. Murayama

Water-in-oil, yes.

Captain Flanagan

The volume ratio of water to oil is 0.8 - is that right?

Dr. Murayama

It's more efficient in regard to micro-explosion.

Anonymous

What is the upper inlet pressure on the homogenizer?

Dr. Murayama

The pressure drop is negligible, because the velocity is one meter per second.

Anonymous

What was the total pressure?

Dr. Murayama

Are you asking for the total pressure of the feed pump?

Captain Flanagan

Yes.

Dr. Murayama

I don't have the exact data, but I think perhaps in the vicinity of one or one-and-a-half atmospheres.

Captain Flanagan

Do you intend to publish these data, or are they perhaps already published?

Dr. Murayama

I'm working on a manuscript at the University of Wisconsin. I hope to present this paper at the next SAE meeting. But as for the emulsifier, if any one here is interested in the emulsifier, I can very easily provide the information on it. And if you wish to use the emulsifier, you can obtain it from the Kinka industry, one of the biggest chemical industries in Japan. I do not represent the industry in any way, but an engineer associated with the industry is working with us. The emulsifier at present is not cheap, because it is being manufactured strictly as an in-plant product. However, if in the future it becomes a mass-production item, it will be available for use as fuel for automobile or marine engines.

Captain Flanagan

Thank you, Dr. Murayama. We have one more presenter who has promised to limit his comments to three minutes. I introduce you to Mr. H. Alliger of Heat Systems Ultrasonics. You've already heard of one application of his emulsor earlier today. Mr. Alliger.

SUMMARY OF REMARKS ON THE
OPERATING CHARACTERISTICS
OF THE SONICATOR DISRUPTOR
ULTRASONIC PROBE

H. ALLIGER

Heat Systems Ultrasonics
Plainview, NY

SUMMARY OF REMARKS OF THE OPERATING CHARACTERISTICS OF
THE SONICATOR DISRUPTOR ULTRASONIC PROBE

H. ALLIGER

Mr. Alliger explained the operation of the ultrasonic probe and its application to fuel emulsions. This device operates by applying an AC voltage to a crystal, causing it to vibrate. These vibrations travel down on a horn that amplifies and concentrates this acoustical energy into the fluid. The alternate compression and rarefaction of the sound waves produce cavitation in the liquid. As the bubbles formed by this cavitation collapse, enormous pressures are produced in the liquid at the distance of 2 to 3 μm from the probe tip. The device has provisions for use in a continuous batch-flow process and for controlling the ambient pressure and temperature. The device is available with flow-rates up to 3 gallons per minute. The larger device is approximately 18" X 18" for the generator, with a 24"-long probe. The power consumption is 2000 watts. Such a unit will produce an emulsion with particle sizes down to 1 μm .

(End of Summary)

Captain Flanagan

I think most of the people who have been working on making emulsions for the last 12 to 15 years are familiar with sonics and sonic principles, and their ability to make emulsions. One of the things that has been brought out is the need to have the appropriate pressure, in making an emulsion, in order to get cavitation to occur where you want it to. This device also must have a certain pressure range in order to make an emulsion. Is that correct?

Mr. Alliger

Well, the idea of getting the pressure around the probe is as follows. When you apply pressure to the fuel oil that you're emulsifying, you remove the air in the fuel oil, and when there's no air in the fuel oil, the intensity within the cavitation

bubble goes up greatly - not one or two times, but ten times, perhaps twenty times, or even one-hundred times. If there's air in the collapsing cavitation bubble and the temperature and vapor pressure go up, the bubble will collapse on an air cushion. In the cavitation process you should try to keep the temperature down and the pressure up. However, with respect to the pressure, there is a maximum pressure buildup at which you get the greatest intensity within the cavitation bubble. If you increase the pressure beyond this maximum, the intensity will go down.

Mr. Wright

You don't have to have increased pressure to make an emulsion. We were able to increase our flow rate with normal pressure. It's true that increasing pressure gives us more intensity, and that's what we used it for. But in most of our work we used normal pressure.

Captain Flanagan

In order to gain more information in the shortest possible time on applicable methods of making emulsions, let us concede that a number of devices are available. Now, what kind of flow rates can be handled with ultrasonics today?

Mr. Alliger

Our largest unit is a 2,000-watt unit, and it will make perhaps three gallons per minute for very fine emulsion, at one micron, on a continuous flow basis.

Captain Flanagan

And its physical size is approximately what?

Mr. Alliger

A foot and a half by a foot and a foot and a half for the generator. The probe is perhaps a foot and a half or two feet long, and four inches or five inches in diameter.

Captain Flanagan

And it's a 2,000-watt unit?

Mr. Alliger

Yes, 2,000 watts.

Captain Flanagan

That really is something.

Mr. Alliger

Right.

Captain Flanagan

Are there any questions that anyone in the audience would like to ask, so that we can wrap it up and move on to lunch?

Professor Harper

Do you have any evidence that these particle sizes are independent of frequency?

Mr. Alliger

Professor Fogler commented yesterday that as you increase the frequency, the particle size goes down. I believe, with Professor Fogler, that that does take place. However, you can get much more energy into the system at the lower frequencies. Thus, at a low frequency you have a relatively large droplet which shows much more activity. A high frequency makes this initial particle smaller, but the net effect at this high frequency is a great reduction in activity. The cavitation bubble is smaller, and you have less intensity inside the cavitation bubble. In summary, the higher frequency gives a better initial effect, but it is quite difficult for the particle to get down to a tenth of a micron at the higher frequency.

Captain Flanagan

It's somewhat misleading to consider the free surface wavelet droplet as a model for a cavitation emulsifying system. They're really different phenomena. Getting energy into the system is what tears up the droplets.

Professor Harper

I'd like you to clear up a point. I thought one of the limitations of ultrasonics is that you cannot have a variable frequency, variable intensity instrument.

Mr. Alliger

You do not have variable frequency. A frequency is fixed by the crystal in back of the probe.

Professor Harper

I think that we who work from a fundamental point of view need variable frequency and variable intensity to give us the desired flexibility.

Mr. Alliger

Obtaining variable intensity is easy. It's just a matter of turning an intensity control dial. However, in my twenty years of experience with ultrasonics, I've never heard of a frequency effect. There is nothing that vibrates at the natural resonant frequency. For example, our wavelength is measured in inches, whereas your emulsion is in microns. The explosion and the collapsing cavitation bubble are the parameters that make the difference. There is no frequency effect. The significant consideration is amplitude.

Professor Thompson

Apart from the frequency problem, there is the additional one that with an ultrasonic device you cannot modulate the flows. This stems from the need to maintain the pressure between the anvil and the hammer area, thus limiting the application to a continuous flow. In other words, in an on-off boiler system, I fail to see how you can put something that size on a diesel engine.

Mr. Alliger

That's not necessarily so. If you have an ultrasonic instrument whose power you can vary, then, when you increase the flow you increase the power. Normally, people use their instrument right to the end. If you use it right to the end, and you

try to increase the flow, you will not get as small an emulsion.

Professor Thompson

I don't think that's the situation. As soon as you increase the flow, you vary the pressure of the fluid which is entering the emulsifier. The emulsifier then exhibits certain difficulties in its ability to produce cavitation at the wave that is distributed forward and back. If I remember correctly, the proprietary unit works at the second harmonic, the frequency at the hammer itself.

Mr. Alliger

Is that Tymponic?

Professor Thompson

Yes. I presume the Tymponic unit is the one you're talking about.

Mr. Alliger

No. There is a degree of similarity, but our unit design is exclusively ours.

Captain Flanagan

Let me first answer Professor Thompson. You can overcome your difficulty by varying the outlet hole. By varying it, you can keep the pressure the same and have a bigger flow.

Dr. Dryer

We were aware of this pressure effect and the gas bubble effect in terms of those experiments I told you about on the internal phase size decay. In fact, we degassed the fuel and operated under an accumulated type system that had a variable pressure on the entire system in addition to the centrifugal pump system.

Captain Flanagan

But isn't it true that you were using essentially the Tymponics ultrasonic device?

Dr. Dryer

No. It was a Cottel type reactor built by Crest Ultrasonics in Trenton, New Jersey. I grant you that there is a similarity to the Tymponics device.

Mr. Alliger

Yes, but remember, there are many of these probes around.

Captain Flanagan

And they have been used in making fuel and water emulsions, certainly in the laboratory. Thank you, Mr. Alliger. Now, we'll leave for lunch and reassemble for our final disucssion period.

(End of Session 4, Section 1)

SESSION 4
SECTION 2
DISCUSSION OF PROPOSED GUIDELINES

SESSION 4
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In the final discussion period of the symposium, guidelines were sought for finding solutions to unanswered questions which were brought up during the previous sessions. Comments were exchanged as to the resolution of conflicting test results described in the existing literature, and suggestions were offered concerning the continued use of the emulsion process in the future development of engine fuels. The discussion began with the following statement by Captain Flanagan.

Captain Flanagan

The attachment on the mailing that was sent to the attendees included guidelines for minimum data reporting in fuel-water emulsion research. For those of you have not brought this with you, there are additional copies on the literature table in the back of the room. I would appreciate it if you would have a copy of this in hand to look at, so that I will not have to repeat or to write down any particular guideline. I think it will make things move faster.

What do we intend to do with these guidelines? We intend to publish them along with the other material we are publishing: paper abstracts, attendees, and discussions. If we can reach a consensus, we will recommend them for researchers who are making, and burning, fuel-water emulsions. We will break down the guidelines into minimum data which should be reported on the emulsion itself, and guidelines for recording work on diesels, gas turbines, and boilers.

SUMMARY OF DISCUSSION
ON PROPOSED GUIDELINES

SUMMARY OF DISCUSSION ON PROPOSED GUIDELINES

Captain Flanagan began the analysis* of the guidelines (see attachment at the end of Session 4, Section 2) by suggesting that the following data should be made available for emulsions (A1):

- o Quantitative chemical analysis of the fuel
- o Trade name
- o Type, additive, and source
- o Presence of natural surfactants
- o Cetane and octane ratings, if applicable.

There followed an exchange of opinions between Captain Flanagan and the members on the floor as to which of these data could actually be obtained, since some data were generally considered proprietary (e.g., fuels and lubricants). After some discussion it was agreed to modify the original list to provide additives, presence of surfactants, and cetane and octane ratings if available.

The next item considered (A2) - pertained to the physical properties of fuel. This included:

- o Viscosity
- o Heat content
- o Density
- o Viscosity index.

Mr. Winkler (Seaworthy, Inc.) commented that caution was necessary on tests relating to the above parameters. His statement was based on the fact that generally, tests on the pure fuel provided data that were invalid for mixtures containing that same fuel.

* Because of time limitation, analysis of the items listed in the attachment was confined to those items considered most significant, and also to items which appeared potentially controversial.

Dr. Shaler (SMS Associates) supported Mr. Winkler's observation by noting that metastable emulsions would bear no relation to the same property of the fuel as far as application was concerned. The properties of the fuel, according to Dr. Shaler, would not be reflected in the emulsion, at least with respect to diesels.

In response to this, Captain Flanagan noted that any report on the burning of an emulsion would be inconclusive without initial baseline data on the pure fuel, and that therefore data on the pure fuel did provide a useful purpose.

There was some question as to whether the cetane rating of an emulsion could conveniently be obtained by the standard ASTM method of observing the boil-off rate. The preferable procedure, according to Captain Flanagan, was to apply a chemical fuel to an engine, change the compression ratio, and determine when it knocks.

Heat content was considered next. The initial assumption was that this information could easily be made available from most handbooks. However, an important point was made from the floor that the source of information was vital for a true representation of the data provided. It was brought out that, for example, No. 6 fuel from Brazil is different from No. 6 fuel obtainable in San Pedro, California, or from No. 6 fuel coming from Norway, or Denmark, or Sweden. Therefore, a proper guideline would be necessary to ensure that the correct fuel is mixed in the preparation of an emulsion.

Viscosity index was discussed briefly, and it was determined to be not vital data, and was removed from the list of data requirements.

Item A1 was still not completely resolved. A participant from the floor returned to this item to discuss the portion of emulsion data relating to chemical analysis of the fuel. This immediately brought up the question of which elements were to be analyzed. Captain Flanagan referred to fuel sent by the U.S. Coast Guard to a private laboratory for standard quantitative chemical tests, which determined the amount of carbon, hydrogen,

and sulfur present. He pointed out, however, that the tests for these elements were not based on ASTM standards, but rather on specific request by the U.S. Coast Guard for these particular quantities.

Mr. Winkler then described the ASTM standards in terms of three separate specifications, identified by number according to their use and degree of complexity. In particular, the fuel specification numbers were categorized as Spec. No. 396 for burner fuel, Spec. Nos. 375 and 975 for diesel fuel, and the most complex, Spec. No. 2880 for gas turbine fuel. Mr. Winkler's categorizations were criticized for not providing actual data beyond specification numbering. He replied that the important aspect of the numbering was that the industry used these numbers as criteria for supplying users with their individual requirements. Beyond that, it was the user's prerogative to provide their own analyses for their own guidelines on fuel obtained by specification number.

The next item (A3) involved consideration of the water source. Mr. White (USCG) asked whether the intent was to aim for a quantitative analysis or for just a source designation, e.g., tap water. Captain Flanagan felt that a quantitative analysis was the preferred objective, especially in the case of the gas turbine, and, in all probability, also for diesels. When his opinion was questioned, he stressed the importance of correlating the results of research with the features that contributed to the results. In support of this, he cited the possibility of a combination of clean fuel mixed with bad water ruining a gas turbine. If no report was forthcoming as to what was in that bad water, then nothing would have been learned from that experience; hence the need for a quantitative guideline on the nature of the water source.

Mr. Winkler added to this discussion by noting that much work was being done recently on investigation of diesel exhaust valve corrosion, especially on modern high-speed, highly turbocharged machines. These investigations indicated that problems associated with formation of sulfides in turbines are being evidenced in diesel exhaust valves also, and that other parameters causing gas

turbine problems are causing similar problems in diesels. On questioning by Captain Flanagan as to the importance of high temperature and high gas velocity with respect to the water source, Mr. Winkler replied that the basic problem is the metal valve temperature, at about 1200° F and up.

Item A6, distribution of water droplet size, came up for discussion. This entailed measurement, where the sample is taken, time elapsed from discharge from the emulsion, droplet size determination, and sensitivity to time.

Dr. Dryer (Princeton University) brought to the group's attention that viscosity, surface tension, and interfacial tension of the emulsion were not yet discussed. They were briefly considered in general terms until Captain Flanagan asked whether regular techniques were adequate means of measurement. Dr. Dryer replied that there were difficulties in measuring each of the properties. He referred, in particular, to a previous discussion by Professor Doohar (Adelphi Research Center, Inc.) of the problems involved in viscosity measurements, and warned against the use of typical annular cylindrical type viscosity measurement systems. Because of very small amounts of creaming at the surfaces of the cylinders, the apparent measured viscosities are much different from the true viscosity. Cone and plate systems, which are possible methods of measurement, also are to a degree questionable, since it is very difficult to avoid creaming in these cases also. Captain Flanagan, in accepting Dr. Dryer's observations, expressed the thought that where the techniques used are difficult and different from classical laboratory procedures, we ought to request inputs from the users when they implement these techniques.

Guideline items relating to the engine were next considered, with Captain Flanagan listing the items included in these categories. Professor Henein (Wayne State University) added some parameters to Captain Flanagan's list, and provided some details on injector size, type, and injector opening pressure, and on the importance of timing of the engine and the injector. According to Professor Henein, the start of injection and the time lag from

the pump reaction to actual injection have to be determined. From this information it is possible to establish static, and possibly dynamic, timing of the beginning and end of injection.

Measurement of cetane and determination of the cetane number were considered for an engine having a variable compression ratio. It was agreed that determining the compression ratio and the ignition delay were applicable to running conditions in a standard engine, which, once it runs, is knocking.

The subject of engine noise was introduced as a drawback which had to be considered. Engine noise appeared to be directly related to use of an emulsion. A discussion then ensued on ignition delay, knocking, and the existence of pressure spikes due to emulsions. Dr. Dryer stressed that from his experience, he failed to notice any pressure spike due to emulsions in low-speed residual fuel oil diesel systems. Captain Flanagan granted that Dr. Dryer's conclusions were correct to the extent of Dr. Dryer's observations, but insisted that there was still sufficient room for future research to come up with more substantial proof of Dr. Dryer's present contention.

Captain Jacobsen (USCG) provided some comments on items B2k and B2c. In the former category, he stated that data should be reported either at actual ambient conditions, or according to some particular standardized ambient conditions. He also referred to the question of injector opening pressure, which is not particularly applicable to all diesel engine fuel systems. He gave an example of a test on a Cummins diesel engine, stressing the need for knowing the calibration card number in order to find, and record, the fuel rates or fuel pressures. Professor Henein commented at this point that in engines other than the Cummins, an injection system using a needle valve requires adjustment of the opening pressure for proper calibration. This, according to Professor Henein, is an important technique, and the injector opening pressure has to be recorded.

Captain Jacobsen's second concern was with data on different degrees of engine loading, namely, idle, midpower, and full load.

Guidelines for application were urgently needed. To illustrate the need, Captain Jacobsen indicated, as an example, the fact that it is especially important to know the correct data for applications where an engine is operating at less than full load in an emulsion fueling capacity. This discussion was expanded to include data not only on loading, but also on the connection between engine speed and loading.

Dr. Murayama (University of Wisconsin) now proposed an addition to B2d. He claimed that during his work on applying emulsions to engines, his associates reported an increase of hydrocarbons and an increase in exhaust odor, resulting in a severe problem in the construction of engines and in installing them aboard ships. This reference to odors triggered a general exchange among the conference members on the problem of identifying odors quantitatively. Captain Flanagan suggested that while odor is a significant factor which should be included in the guidelines, it ought to be regarded subjectively, and no attempt should be made to apply any numerical value to it.

There was renewed discussion on item B2c concerning the relationship between engine speeds and loads. Questions arose as to whether the guideline was to specify particular loads at rated speed, corresponding to an engine's actual requirements at the time of its sale, or whether the guideline should include an engine's capability for idle or lesser speeds with varying loads to meet conditions other than actual engine performance. The general consensus on this was to appoint a subcommittee of experts in the industry, and to have it, at some future time, issue a decision adaptable to the entire industry.

ATTACHMENT
GUIDELINES FOR MINIMUM DATA REPORTING IN FUEL/WATER
EMULSION RESEARCH

It is understood that many technical journals, conventions, and symposia have page limits for technical papers. If the guideline material cannot be included in the body or the appendices of a technical paper, it is recommended that authors collect and make available on request the guideline data to colleagues. The paper should indicate that data so available.

These data are considered essential to advancing the understanding of the phenomena or in evaluating the concepts worth. If cost and time demand modest efforts, data not marked with # should be deleted first.

A. The Emulsion:

- #A1. A quantitative chemical analysis of fuel. Trade name. Type. Additives. Source. Presence of natural surfactants. Cetane/Octane rating (if applicable).
- A2. Physical properties of fuel. Viscosity. Heat content. Density. Viscosity Index.
- A3. Water source. Quantitative analysis.
- A4. Temperature of mixture before and after emulsifying. Temperature when delivered for burning.
- #A5. Percent water in emulsion by volume or weight (specify which). Method of determining percentage. Accuracy of percent determination.
- #A6. Distribution of water droplet size. How measured. Where sample taken. Time elapsed from discharge of emulsor and droplet size determination. Sensitivity to time.
- #A7. Type of emulsor. Trade name, model, or available details if experimental. Flow rates. Pressures

ATTACHMENT
GUIDELINES FOR MINIMUM DATA REPORTING IN FUEL/WATER
EMULSION RESEARCH (CONTINUED)

before and after emulsor. Physical principles used in emulsion formation.

#A8. Piping diagram showing return flows, sample points, fittings, sizes, and components (pumps by type, orifices, etc.)

#A9. Total energy rate into emulsor.

#A10. Special additional treatment such as surfactant additions, additional agitation, etc.

B. Burning in Compression Ignition Engines:

#B1. Engine type, model, number of cylinders, bore, stroke, compression ratio, configuration, injector size and type, condition, aspiration, and valve timing.

#B2. Baseline performance data on pure fuel to include:

#B2a. RPM, fuel flow, torque or horsepower, exhaust temperature, intake air temperature and humidity.

#B2b. Type and accuracy of load determination (dynamometer).

#B2c. At least idle, midpower, and full load data should be taken. More data points desirable.

#B2d. Exhaust gas analysis including smoke and particulates.

B2e. Governor and rack settings if available.

#B2f. Timing of beginning and end of injection.

B2g. Cylinder pressure versus crank angle if available.

B2h. Presence of detonation knock.

ATTACHMENT
GUIDELINES FOR MINIMUM DATA REPORTING IN FUEL/WATER
EMULSION RESEARCH (CONTINUED)

- B2i. Upstream and downstream pressures and temperatures around turbochargers and blowers.
- B2j. Lube oil type and condition before burning emulsion (fuel dilution, viscosity, acid, sludge, water).
- B2k. Ambient temperature, coolant temperature, lube oil temperature.
- B3. Emulsion burning data.
 - #B3a. Same as A5, A6, A8, A9.
 - #B3b. Same as B2a, B2c, B2d, B2e, B2f, B2g, B2h, B2i, B2k.
 - B3c. Lube oil condition after specified hours running on emulsion.
 - B3d. Any change in the condition of injectors, fuel pumps, piston, or rings after specified hours.
- C. Burning in Spark Ignition Engines:
 - #C1. Baseline data from running on pure fuel. Same as B1 except delete injection and add ignition type, timing, spark plug data.
 - #C2. Actual emulsion burning tests. Provide data as with diesels above with appropriate allowance for engine differences.
- D. Gas Turbines:

Essentially same data as C. with the addition of combustion chamber temperatures and inner spindle rpms if applicable. Thrust mass flow-rate should be recorded if a free turbine is not used. If free turbine is used, torque and free turbine rpm or HP as well as up and down stream temperatures are required.

ATTACHMENT

GUIDELINES FOR MINIMUM DATA REPORTING IN FUEL/WATER
EMULSION RESEARCH (CONTINUED)

E. Boilers:

- E1. A complete description of the boiler is needed including burner and tip sizes.
- #E2. Baseline data should be collected on pure fuel based on measured exhaust gases at minimum excess air and smoke number specified (Bacharach or equivalent) not exceeded.
- #E3. Stack gas analysis should be repeated with emulsion burning at minimum excess air and smoke number not exceeded.
- #E4. Steam flow rates and pressures should be carefully reported.
- E5. Fireside and waterside cleanliness should be carefully reported before and after each test with hours on emulsion reported.
- E6. Water vapor in flue gas is important.

F. All Cases:

- #F1. Specify and show the allowance for heat content of surfactants used in calculating efficiencies.
- #F2. Specify and show the energy absorbed by the emulsifying equipment in computations of efficiency.

(End of Session 4, Section 2)

SESSION 4

SECTION 3

SUMMARY OF PRESENT TRENDS AND FUTURE GOALS FOR APPLICATION
OF WATER-IN-FUEL EMULSIONS IN COMBUSTION PROCESSES

SESSION 4

SECTION 3

SUMMARY OF PRESENT TRENDS AND FUTURE GOALS FOR APPLICATION OF WATER-IN-FUEL EMULSIONS IN COMBUSTION PROCESSES

INTRODUCTION

The final discussion of the conference involved an evaluation of existing activity with respect to water-in-fuel emulsions, and also an attempt to analyze the future potential contribution of the emulsions to fuel efficiency, fuel economy, compatibility with diesel engines, and environmental requirements. The question of adequate means of researching the field was the first item discussed.

RETROFITTING AND NEW PRODUCTS

It is a popular belief that most of the diesel engines that are going to be in use in the foreseeable future have already been manufactured, and are actually in use now. Since there are at present vast numbers of combustion processes throughout the world, it would be quite proper to think of the possibilities of retrofitting the many existing systems according to the most modern concepts. Implementing the proposed changes would contribute to improved efficiency and to minimization of pollutants.

At the same time, there is the question of the extent of research to be performed on new products. For example, if a new emulsor were to be produced which could satisfy increased performance requirements, there might be some question as to how much research effort ought to be expended in new designs of diesel engines, and boilers, and gas turbines. Then, too, decisions might have to be made on whether to emphasize NO_x reduction or improvements in combustion. The question of research for new products and accompanying equipment design changes merits careful study.

GUIDELINE OBJECTIVES

Two objectives must be considered in establishing acceptable guidelines: commercial and academic.

COMMERCIAL OBJECTIVE

This objective is reflected in the need for suitable water-in-fuel emulsions. There is a related factor which should be considered, i.e., elimination of surfactants. For example, in transportation systems such as shipping and air traffic, it will be necessary to bunker at locations where fuel is available. In this case, putting in surfactants could pose a problem.

ACADEMIC OBJECTIVE

The academic objective relates to the need for the industry to understand thoroughly the factors involved in setting up reliable systems at low first cost. For this objective to be realized, academic projects would be created to investigate methods and techniques for satisfying this need.

POTENTIAL AREAS FOR FULFILLMENT OF OBJECTIVES

Three approaches are presented to illustrate the potential areas in which the commercial and academic objectives can be realized:

1. The possibility of redesigning boilers

With further investigation of the design of ship boilers, it might be possible to minimize, or even eliminate, complex auxiliary equipment associated with air heaters.

2. Improvement of the gasoline engine

Further experimentation on gasoline engines can provide improved operation capability.

3. Application of residuals or solids in fuels

Methods could be devised to provide a catalytic effect for burning of residual matter (e.g., dross left over from coal mining processes) to use up combustible material within the residual matter. This would make available additional energy supply from sources heretofore considered pure waste.

PROBLEMS RELATED TO FUTURE PRACTICE IN COMBUSTION PROCESSES

The discussion turned to what could be contemplated for the future in the matter of problems associated with the combustion processes. A suggestion was made, and followed, to translate these problems into short-term and long-term goals.

SHORT-TERM GOALS

Short-term goals were defined as centering on problems outstanding and likely to predominate for intervals up to about ten years. The short-term problems implied present awareness of their existence, and the question of whether existing conditions could be improved by addons, e.g., adding of emulsions. In addition, short-term problems included such inquiries as what was needed for boilers, gas turbines, diesels, and spark ignition engines to obtain best results.

Three basic goals were specified for which guidelines were to be established, and on the basis of which it was hoped that efforts would be made to realize their short-term potential. These goals were:

1. Reduced pollutants.
2. Improved combustion efficiency.
3. Ability to burn cheaper fuel.

The opinion was expressed, though not wholly endorsed, that emulsification could possibly satisfy all three goals.

A number of suggestions were made as to how to approach these goals. These included recommendations for the Federal Government to provide money for research on emulsions, investigation of residuals rather than distillates with respect to the short term, easily applicable retrofit emulsion systems, and separate studies of boilers and furnaces to assess the energy and dollar impacts by industry type. The Federal Government was encouraged to provide much greater funding for research on boilers or furnaces of large-scale industrial systems. Since current data applied to boiler systems of capacity not greater than about 35,000 pounds per hour, it was felt highly desirable that the program should be expanded to look into systems ranging up to capacities of about 100,000 pounds per hour.

The discussion continued as to the justification for requests from the Federal Government for funding of various projects. An important fact was brought out that seemed to substantiate the legitimacy of these requests. The Energy Policy Conservation Act of 1975 states that in some cases energy impact statements are to be developed for certain situations. In order to convince the Government, a high degree of credibility had to be established. In the case of emulsions, this credibility could readily be established, because, in tests and actual operation, not only did emulsions not evidence any detrimental characteristics, but they were in fact shown to improve emissions, and the efficiency of particular diesels. These facts, plus the on-highway situation of enormous consumption of the nation's petrochemical supply, should provide conclusive inducement for the Government to agree to the funding proposal. Emulsification, even if applied only to buses and trucks, could result in a great saving of fuel. This reasoning bolstered the thinking that funds might be forthcoming in answer to properly presented requests.

RELATIVE IMPROVEMENTS FROM APPLICATION OF EMULSIONS

There were additional statements favoring continued work on the application of emulsified fuels and affirming the validity of

requests for funding such work. On the question of efficiency, the greatest benefit from the use of emulsified fuel was derived on application of the fuel to equipment of relatively low-efficiency. This point was brought out in the distinction between seagoing boilers, with efficiencies of about 85 to 90 percent, and boilers typical of domestic and small industrial systems, in which the efficiencies ranged in the mid-Seventies. In the latter case, there was easily room for an improvement in efficiency of at least five percent.

The second beneficial characteristic of the emulsified fuel was illustrated by reference to its application in the gas turbine. Since the large air-fuel ratio in a gas turbine makes possible extremely high combustion efficiency, the question of increased efficiency in combustion for the gas turbine is of small consequence. However, with use of emulsified fuel, the gas turbine evidences an improvement in the NO_x count; actually, a count reduction to below the new specification of 75 parts per million.

Finally, the diesel engine can benefit both from the standpoint of improved efficiency in fuel consumption, at least 5 percent, and of reduction in the NO_x and smoke count of about 50 percent. These improvements could cause a significant economic impact with respect to costs and the saving of fuel.

The factors described above should serve as impetus for investigation the emulsification process further to determine why these beneficial results are attainable. An understanding of the process would substantiate the existing empirical data, and would spur further analysis to perhaps increase the potential benefits to be obtained.

A suggestion was made to consolidate the ideas expressed on the use of the emulsified fuel in order to arrive at a consensus. Questions were then asked concerning fuel extension under off-load conditions in diesels, and determination of the amount of smoke and particulates that might be considered safe for boilers that could burn heavier fuel. Many suggestions were made, including cleaner burning, flexibility of operation, fuel choice, reduction

in maintenance requirements, and reduction of fire hazards.

LONG-TERM GOALS

The first long-term goal suggested was the possibility of improving staged combustion, which was relevant to fuel-nitrogen conversion. The improved staged combustion was introduced as a factor to be investigated for improvements in burning efficiency and in the ability to reduce the NO_x count.

Another topic of special concern for the long-term goal had to do with low-speed, heavy-fuel-burning diesels. It was predicted that these diesels, which had been phased out over the last 20 years, would make a significant comeback. This prediction was based on the fact that diesels could be powered by a fuel of which the Third World has a permanent source of supply and of the type that did not require a high degree of maintenance. Also, these diesels could burn almost anything, especially with water emulsions.

The above statements to the group were uncontested, with the exception of one contrary viewpoint. The group was urged to consider the sulfur content and emission requirements of the fuel that the low-speed diesel was going to burn. The Clean Air Act had the effect of steering the trend away from heavy, contaminated fuels. Therefore, even though the low-speed diesels could very efficiently use the heavy fuel, it was necessary to understand that, so long as the Clean Air Act remained in the statute books, the advantage of the low-speed diesel with respect to free use of heavy, contaminated fuel would have to be considered within the context of the limitations stated in the Clean Air Act.

At this point in the long-term goal discussion, a proposal was made concerning an approach to the realization of the long-term goals as well as of the short-term goals. The proposal recommended the setting up of a list specifying both types of goals. This list would include, among other provisions, tradeoffs which would determine short-term and long-term economic impacts,

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TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MASS
PROCEEDINGS OF SYMPOSIUM ON WATER-IN-FUEL EMULSIONS IN COMBUSTI--ETC(U)
SEP 78 R WALTER, J WHITE

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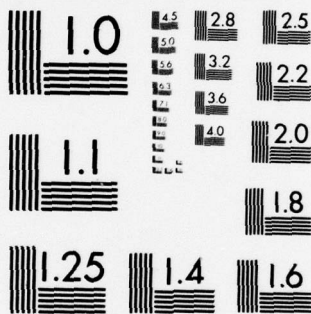
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and so provide the basis for rational requests for funding by the Federal Government.

The final item of concern on the long-term basis related to the potential for the future use of diesel engines in the automotive field to meet a 1985 standards requirement of 27.5 miles to a gallon of fuel. The diesel engine, however, might not comply with the maximum allowable NO_x and smoke emission requirements. This prompted the suggestion of a tradeoff: gasoline conservation for the price of relaxation of pollution restriction.

All the recommendations were accepted, with the intention that concrete proposals would result from their having been aired. The conference ended with an expression of thanks from Chairman Flanagan to all the participants for attending the conference and sharing in the proceedings.

(End of Session 4)

(End of Conference)

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